

TECHNICAL MANUAL

**HEATING, VENTILATING AND
AIR CONDITIONING (HVAC)
CONTROL SYSTEMS**

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(HVAC) CONTROL SYSTEMS

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Chapter 1

General

1-1. Purpose

This manual provides criteria and guidance for the design of heating, ventilating and air conditioning (HVAC) control systems, and designates the standard control loops to be used.

1-2. Scope

This manual describes frequently encountered control-system loops, provides examples of how these loops are used, and provides guidance and criteria for the design of standard HVAC control systems and standard control panels. This manual does not provide guidance on selecting HVAC systems and does not prohibit selection of system types not included herein.

1-3. References

The following documents form a part of this manual to the extent referenced:

- a. Government Publications TM 5-785, Engineering Weather Data.
- b. Government Publications TM 5-815-2, Energy Monitoring and Control Systems.

1-4. Policy.

a. Adherence to the standards. The design of the HVAC control systems will not deviate from the standards established in this technical manual, except where the design agency has approved a waiver request.

b. Control-system designer responsibilities. The HVAC control-system designer will be responsible for designing each control system required for the project HVAC systems, and will incorporate the control loops, control-system sequences of operation, and HVAC control-panel layouts, using the symbols, abbreviations, and acronyms designated in this manual. This design responsibility requires producing a design package that includes a specification, a set of drawings, and commissioning procedures for each HVAC control system. The designer will not depend on any HVAC control-system vendor for the design of the HVAC control systems.

c. Control-system vendor compliance. The HVAC control-system vendor will be required by the contract documents to make the system product-specific. The specification will require the HVAC control-system vendor to produce shop drawings, schedules, instructions, test plans, test procedures, commissioning procedures, and other documents showing the application of products to implement the control-system design. The specification will require that the HVAC control-system vendor test the control system and document the test to show that the control system functions as designed, and to commission the control system.

1-5. Control-system designer guidance

a. Control-system loops and control logic. The manual includes descriptions of loops for controlling temperature,

humidification, airflow, and duct-system static pressure. In addition, the manual contains control logic for the following:

- (1) Scheduling and initiating system operation.
- (2) Changes in control modes of operation.
- (3) Normal interlocks.
- (4) Life-Safety system interlocks.
- (5) Special interlocks (such as for freeze protection).
- b. Control-system variations. The manual shows some of the possible HVAC-system equipment and control-system variations, and provides guidance and examples to show how the designer can modify control loops and systems for applications not specifically shown. The HVAC equipment and system variations for which control-system guidance is provided include:
 - (1) Outside-air preheat coils using hot water or glycol.
 - (2) Outside-air preheat coils using steam.
 - (3) One-hundred-percent outside air in lieu of outside-air/return-air economizer.
 - (4) Deleting economizer control.
 - (5) Return fans.
 - (6) Exhaust fans.
 - (7) Humidity controls.
 - (8) Smoke dampers in HVAC supply-air and return-air ducts.
 - (9) Override of control of valves and dampers for freeze-protection or smoke-control systems.
 - (10) Startup and shutdown of HVAC fan systems by external systems such as smoke control.
 - (11) Variable-speed fan drives.
 - (12) Combining systems in a common control panel.
 - (13) Unoccupied-mode space-temperature setback control of HVAC equipment.
 - (14) Building purge and recirculation modes.
 - (15) Variations in the use of control valves.

c. Project applicability. The HVAC control systems shown in this manual are applicable to new-construction building projects, building-addition projects, building-renovation projects, and (as further described in chapter 6) building-retrofit projects.

d. Types of HVAC equipment covered. This manual provides control-system guidance for HVAC systems for heating, cooling, humidity control, ventilation and air delivery, terminal units, and small packaged unitary systems. Terminal units include Variable Air Volume (VAV) boxes, duct coils, fan-coil units, unit heaters, gas-fired infrared heaters, and radiators.

e. Exceptions. This manual does not cover systems for HVAC equipment such as boilers and chillers, which usually have controls integral to the equipment.

1-6 Design concept

The guidance contained in this manual adheres to a particular concept for designing HVAC control systems. This concept includes the use of standard control systems that incorporate standard control loops and standard control-system devices. The manual shows which devices are housed in a standard HVAC system control panel. The design concept also includes the use of digital single-loop controllers for the control of air-handling systems and

hydronic systems. The use of these controllers for such systems has been tested in the laboratory and in the field.

1-7 Control-system standards

a. *Standard instrumentation signals.* The HVAC control-system transmitter signals and the single-loop controller signals will be standard instrumentation signals of 4 to 20 milliamperes, which can be readily interfaced with most types of energy monitoring and control systems (EMCS). When required, the controller output signal will be converted to 3 to 15 psig.

b. *Actuators.* Actuation of valves and dampers for HVAC systems such as air-handling units and convertors will normally be by pneumatic actuators. This manual also provides guidance on substituting electric or electronic actuators for pneumatic actuators.

c. *Terminal-unit control*

Systems. Terminal-unit control systems will use only electric or electronic control devices. The foregoing requirement for standard instrumentation signals does not apply to terminal-unit control systems.

d. *Standard controller.* A single version of an electronic, self-tuning controller (generally known as a digital single-loop controller) will be used as the standard controller for HVAC systems in all applications except for terminal-unit control-system applications. This type of controller has a history of reliable use, and is available from multiple sources as a standard product with the features described for its use in this manual. Using a standard controller will make control systems easier to maintain. The standard controller will accept one analog signal as a process variable input (PV) and one analog signal as a remote setpoint adjustment (CPA) input, and will produce one analog output signal (OUT). The controller will fit in a standard-size panel cutout. A controller of one manufacturer may be replaced by a controller of another manufacturer because several manufacturers produce the same version of the controller.

1-8 Project implementation

a. Impact of other design disciplines on control-system design. Design of HVAC control systems is largely driven by decisions on the overall-building HVAC mechanical and electrical design. Therefore, design of the HVAC control system must be incorporated into the overall design process to ensure adequate consideration of the space requirements for the HVAC control system's mechanical and electrical support services. Early involvement of the HVAC control-system designer in the project can help prevent unfortunate HVAC system design choices that could result in marginally-controllable HVAC systems. The control-system designer's involvement should start with the development of the design concept and continue throughout the design process. The control-parameter criteria (temperature, humidity, pressurization, occupancy schedules, etc.) must be defined for all systems. These criteria are the starting point for the HVAC control-system design. The controller setpoints are shown on the HVAC control-system contract drawings and are based on the HVAC system design criteria. The setpoints are guidance

for maintenance of the control systems.

b. Reuse of existing control devices. Renovation and addition projects require extra engineering work in the form of a detailed field survey of existing HVAC control systems to determine if existing control devices can be reused for the project, and, if so, the extent to which they require modification. Devices that use standard 4-20 milliampere of 3-15 psig signals are among those which possibly may be reused. The contract drawings must show control devices that will be reused, replaced, modified, or removed.

c. Locations of control devices. The designer will show the locations of wall-mounted instruments, HVAC control panels and outside air sensors, transmitters, and sunshields on HVAC floor-plan drawings. The designer must show the location of sensing elements and primary measuring devices on the HVAC system drawings. An exception to this requirement is the sensing location of the duct-pressure instrument for the supply-fan pressure-control loop of a Variable Air-Volume system; this sensing location is determined by the installed ductwork configuration. This requirement is intended to ensure that design consideration is given to these details so that the sensing will be proper and accurate, and to provide for clearance and access for maintenance of the control system. The locations of thermometers and pressure gauges should be selected for normal visual access by personnel required to read them.

d. Control-device clearance and access. Control-system elements must not intrude upon the space required for mechanical- and electrical-system maintenance access. The control-system design must be coordinated with the HVAC-system design to provide ductwork access to install sensing elements and transmitters.

e. Location of permanent instrumentation. The location of the permanent instrumentation thermometers, spare wells, and valved outlets for gauges in piping systems must be coordinated with the HVAC system design and must be shown on the HVAC-system contract drawings. Sufficient access space must be provided in the ductwork downstream of each air-flow measurement sensor and array, to allow for a traverse with a portable instrument for calibration purposes.

f. Coordination with electrical-system design. The designer will coordinate the control-system design with the electrical-system design to show power circuits for HVAC control panels, air compressor, and drier.

1-9. Design-package requirements for HVAC control systems

a. *Drawings.*

(1) The designer will include standard HVAC control-panel drawings to describe control-panel construction and mounting arrangements as shown in chapter 4. These drawings are:

- (a) Standard wall-mounted HVAC control-panel arrangement.
- (b) Standard HVAC control-panel interior door.
- (c) Standard HVAC control-panel back-panel layout.

- (d) Controller wiring.
 - (e) Supply-fan and return-fan starter wiring.
 - (f) Exhaust-fan and pump-starter wiring.
 - (g) HVAC control-panel power wiring.
 - (h) Damper schedule.
- (2) Some simple control systems do not require a control panel and would not require panel drawings.
- (3) the schematic will show control-loop devices and other permanent indicating instrumentation (such as pressure and draft gauges, thermometers, flow meters, and spare thermometer wells). The indicating instrumentation is intended to permit a visual check on the operation of the HVAC control system.
- (4) Control systems for HVAC often require connections to boiler-control systems, chiller-control systems, variable-speed drives, fire-alarm and smoke-detection systems, and EMCS. The schematic and the ladder diagram will show the interface points between field-installed HVAC control systems, factory-installed HVAC control systems, and other control systems.
- (5) The ladder diagram will show the relationship of the devices within the HVAC control panel and their relationship to HVAC equipment magnetic starters and other control panels.
- (6) The equipment schedule will show the information that the vendor needs to:
- (a) Provide instrumentation of the calibrated ranges.
 - (b) Select control valves and associated actuators.
 - (c) Adjust the control-system devices for sequencing operations.
 - (d) Configure the controller parameters, such as set-points and schedules.
 - (e) Set the control-system time clocks.
- (7) The interior-door layout will show the controllers, switches, pilot lights, pneumatic receiver gauges, current signal-to-pneumatic signal devices, and other door-mounted devices.
- (8) The back-panel layout will show the location of all other panel-mounted devices, and will assign a back-panel area for terminal blocks.
- (9) The terminal-block layout will show the location of specific terminal locations according to their function, and the locations of spare terminals and unassigned spaces.
- (10) The drawings will be those shown in chapter 4 of this manual for the standard HVAC control systems, with site-specific modifications and any additional control-system loops required. The number of contract drawings necessary to show each control system varies with the system size and complexity. Most control systems in this

- manual can be shown with the schematic, ladder diagram, and equipment on one drawing, and control-panel details on two drawings.
- b. *The HVAC control-system specification.*
- (1) Because the HVAC control-system designer has the responsibility to completely design the control system, the specification requires more technical detail than would be required if the designer needed to specify only the end-performance result of control. The performance-type specification approach used in the past allowed the vendor more latitude in the selection of control devices, in the construction of control loops, and in the construction of HVAC control panels.
- (2) The designer must now specify more extensive vendor submittal requirements than had previously been required. The submittals required are shop drawings, commissioning procedures, operating and maintenance instructions, training-course documentation, a calibration-commissioning-adjusting report, testing documentation, and a list of service organizations.
- (3) The control devices to be used must be specified in detail.
- (4) Because the control system is electronic and can interface with various EMCS, the requirements for electrical surge-protection devices installed in the system wiring must be specified, both to protect the HVAC control system and to prevent surges on HVAC control system wiring from adversely affecting the EMCS.
- (5) Each control system must have a sequence of operation and a commissioning procedure.
- c. *Sequence of-operation.* Each control system will have a sequence of operation. The sequences will be included in the project specification or they may be shown on the contract drawings. Where the project HVAC systems are similar, the control loops and logic having identical control functions will be described identically in the sequences. The text of the sequences will vary only to the extent necessary to describe the operation of dissimilar control loops and logic.
 - d. *Commissioning procedure.* The project specification for each control system will include a commissioning procedure. The commissioning procedure is a four-step process that details how the vendor will inspect, calibrate, adjust, and commission each HVAC control system. The types and quality of calibration instrumentation to be used in the procedure and the extent of documentation of the procedure will be specified. Where project HVAC systems are similar, the requirement for applying the procedure to control loops and logic will be

described identically in each procedure. The text of the procedures will vary only to the extent necessary to describe the application of the commissioning procedure to dissimilar loops and logic. The four steps of the commissioning procedure are as shown in table 1-1.

Table 1-1
Commissioning Procedure

Step: 1.
Activity: System inspection.
HVAC-system condition: Shut down.
Purpose: Observe system for position of valves and dampers, and readiness of HVAC control panel.
Step: 2.
Activity: Calibration accuracy check.
HVAC-system condition: Shut down.
Purpose: Collect one data point for each sensing element, transmitter and controller combination under steady-state conditions.
Step: 3.
Activity: Actuator range adjustments.
HVAC-system condition: Shut down.
Purpose: Set full-stroke travel of actuators matched to controller output range.
Step: 4.
Activity: System commissioning.
HVAC-system condition: Operating.
Purpose: Collect second data point for calibration accuracy check, tune controllers, observe control of HVAC system in each mode of operation, and observe the operation of safety devices.

1-10. Control-system Interface to EMCS

- a. Transmitters and control point adjustment (CPA). The control-system design will show HVAC control-panel terminal blocks showing installed jumpers for interfacing control-system transmitters with EMCS. Removal of these jumpers allows EMCS to connect devices in series with the 4- to 20-milliampere current loop. The EMCS devices read the HVAC transmitter signals to the HVAC system controllers. Terminal blocks that allow connection of the single-loop digital controller's remote-setpoint input to a

- CPA signal from EMCS will be shown. For information on EMCS reference TM 5-815-2.
- b. Status and shutdown devices. Low-temperature-protection thermostats, smoke detectors, and high-static-pressure shutdown switches operate relays in the HVAC control-system logic to perform the required control functions. Contacts of these relays are wired to terminal blocks in the HVAC system control panel for EMCS use. Differential-pressure switches in the air-handling-system filters will have a contact in the device reserved for EMCS use.
 - c. Override of HVAC control systems by EMCS. The control-system ladder diagrams and HVAC control-panel details will show provisions for:
 - (1) Replacing HVAC control-system time clocks by EMCS start-stop contacts.
 - (2) Installing an EMCS override of the HVAC system's economizer-mode controller signal.
- 1-11. Fan-starter control-circuit override by external control systems
- The ladder diagrams for fan-starter control circuits will show provisions for shutting down the fans and for overriding low-temperature safety thermostats and smoke detectors to start the fans from external systems. These provisions are intended to allow interface with smoke-control systems.
- 1-12. Coordination with HVAC system balancing
- The project specification will require that balancing is completed, that minimum damper positions are set, and that a balancing report is issued before control systems are tuned. Other control-system commissioning activities may be performed independently of HVAC system balancing.
- 1-13. Explanation of Terms
- Terms, abbreviations and acronyms are shown in the glossary, section I.
- 1-14. Symbols
- Standards symbols used in this manual are shown in the glossary, section II.
- 1-15. Figures
- All figures are located at the end of each chapter.

Chapter 2

HVAC Control System Equipment, Equipment Uses and HVAC Control Loops

2-1. General

a. The design of HVAC control systems is implemented by defining the operating modes of the HVAC equipment, defining the control loops required, and selecting the control system equipment to be used in the loop. The process of selecting the control system equipment includes calculations by the designer to specify the flow capacity of control devices, the physical size of control devices and the electric service required.

b. This chapter describes the operating modes, process variables, control, modes, control-system devices and their features, control system equipment applications, and inter-connection of control devices. This chapter provides criteria and guidance for selecting and sizing control devices.

2-2. Control of HVAC-system operating modes and process variables.

a. Control-system operating modes. Control systems start and stop the HVAC systems according to a time schedule, and at specific outside-air temperatures and specific indoor temperatures. In addition, the control systems operate the HVAC systems in the following modes of operation:

(1) Occupied mode is initiated automatically to allow HVAC systems to start in sufficient time to bring the space to the proper temperatures at the start of occupancy.

(2) Ventilation-delay mode is initiated automatically to prevent the use of outside air when the unit is started prior to occupancy, to cool down or warm up the area served.

(3) Unoccupied mode is initiated automatically to prevent unnecessary operation of HVAC-system equipment during periods of non-occupancy except for special purposes such as operation to maintain minimum space temperatures for freeze protection.

(4) Heating or cooling modes are initiated manually to provide either heating or cooling media to HVAC equipment.

b. Control of HVAC-system process variables. While the HVAC systems are in operation, the process variables commonly sensed and controlled by HVAC control systems are:

- (1) Temperature.
- (2) Relative humidity.
- (3) Static pressure of air.
- (4) Differential pressure of air.
- (5) Air-flow rate.

c. Constraints on process variables by operating modes. The constraints placed on the control of HVAC process variables by the operating modes are:

(1) Cooling and humidification are shut off during the unoccupied mode.

(2) Outside air is not supplied to the space during the unoccupied and ventilation-delay modes.

d. Modulating control. The amount of heat delivered to a space (or removed from a space) from certain types of HVAC equipment is regulated by varying the heat-exchanger capacity from zero to one-hundred percent in response to the variation of a continuous, gradual input signal. This is called modulating control. Heat-exchanger control valves, mixing dampers, fan-inlet vanes, variable-speed drives, and humidifier valves are examples of HVAC equipment that are controlled by modulating control.

e. Two-position control. The amount of heat delivered to a space from certain types of HVAC equipment is controlled by turning the equipment on and by shutting the equipment off. This type of control is also called on-off control. Examples of 2-position control are the starting and stopping of the fans of unit heaters and fan-coil units by room thermostats to maintain space temperature, and the opening and closing of shut-off dampers when fans are started and stopped.

2-3. Control-system equipment.

a. Control valves.

(1) Control valves are used to regulate the flow of fluids in piping systems by compressing and releasing a valve spring to move a valve-closure disk or plug toward or away from the closure seat of a flow port. The valves are used both in modulating and in 2-position control applications.

(2) Examples of the use of modulating control valves are:

- (*a*) Heating- and cooling-coil control valves.
- (*b*) Converter steam-control valves.
- (*c*) Humidifier control valves.
- (*d*) Perimeter-radiation-systems zone valves.

(3) Examples of the use of 2-position control valves are:

(*a*) Dual-temperature water-system changeover valves.

(*b*) Shut-off valves used in fan-coil unit coils.

(4) Control valves are classified according to their flow-regulating body patterns. A 2-way valve restricts fluid flow in one direction, because it has one inlet and one outlet; a 3-way valve restricts flow in two directions. The designer will use 2-way control valves for controlling the following types of HVAC equipment:

- (*a*) Convertors.
- (*b*) Radiators.
- (*c*) Coils served by variable-volume pumping systems.
- (*d*) Steam coils.

(5) A 3-way mixing valve has two inlets and one outlet, and a 3-way bypass (diverting) valve has one inlet and two outlets. For the systems shown in this manual, the 3-way mixing valve is used in both flow-mixing and flow-diverting type applications, except that a 3-way bypass valve is used as a dual-temperature changeover control valve.

(6) In the flow-mixing application, the 3-way valve is used to mix heated primary flow, from a boiler or a converter, with system return flow to produce system secondary supply, for the purpose of controlling temperature. When used on the return line from a coil, one of the 3-way valve's inlets is from the coil, and the other inlet is from the bypass around the coil. The designer may choose to use 3-way mixing valves in lieu of the 2-way valves shown in this manual for controlling the following types of HVAC equipment to prevent deadheading of pumps:

(*a*) Coils served by constant-volume pumping systems.

(*b*) As means of pump pressure relief in variable-volume pumping systems.

(*c*) As perimeter-radiation-zone valves.

(*d*) As diverting valves around boilers or cooling towers.

(7) The designer may choose to use either four 2-way valves or one 3-way mixing valve, and one 3-way bypass valve for 2-position flow-control applications as dual-temperature-system changeover valves.

(8) Control valves are classified according to the action of the valve spring in moving the disk or plug relative to the seat when the control signal or the power is removed. A 2-way valve that opens its flow port under this condition is called a normally-open (NO) valve, and one that closes its flow port under this condition is called a normally-closed (NC) valve. A 3-way mixing valve has both NC and NO inlet flow ports connected to a common (C) outlet flow port. A 3-way bypass valve has both NC and NO outlet flow ports connected to a C inlet flow port.

(9) The flow-regulating characteristic of a valve is generally determined by the shape of a disk or plug that passes through the flow port. The flow-regulating characteristics used for control systems covered by this manual are:

(*a*) Linear flow, in which the percent of valve travel equals the percent of maximum flow rate through the valve.

(*b*) Equal-percentage flow in which equal increments in the percentage of valve travel produce an equal-percentage change in flow rate from the previous flow rate, when a constant pressure drop is maintained.

(10) The applications of 3-way mixing valves covered by this manual require the use of valves with linear flow characteristics. The applications of 2-way valves covered by this manual require the use of valves with equal-percentage flow characteristics. This requirement results from the application of the valves as modulating fluid-control devices. The equal-percentage-flow characteristic matches the non-linear heat-exchange characteristics of the HVAC equipment coils with a change in fluid flow that tends to linearize the heat-exchange output of the coil with a linear signal to the control valve. The linear-flow characteristic is more suitable for mixing applications and for humidification.

(11) The purchase price of a control valve increases with its size. The installation cost of a control valve also increases with its size, because of:

(*a*) The change from screwed ends to flanged ends

(*b*) Because larger valves and their weight require more installation and handling labor.

(12) At a pipe size of 4 inches or larger, a type of rotary control valve (known as a butterfly valve) becomes economically suitable for HVAC control applications because of the combination of the price of the valve and the installation costs. The butterfly valve has a disk that rotates on a shaft and closes against a seat. The seat is concentric with the connected pipe. The butterfly valve can have flow-control characteristics similar to equal percentage when used with an appropriate actuator and positioner. In three-way applications of valves for 4-inch pipe size and larger, the designer will show two valves on a common pipe tee, with separate actuators that will operate the two valves simultaneously. One of the valves will be NC, and one will be NO. The C connection can be either an inlet or an outlet. This allows the combination of 2 valves and a pipe tee to function as a 3-way mixing valve or a 3-way bypass valve. Figure 2-1 shows butterfly valves used in 3-way mixing and 3-way bypass arrangements on a common pipe tee.

b. Control dampers.

(1) Dampers are used to regulate the flow of air in ductwork in both modulating and 2-position control applications.

(2) Examples of the use of modulating dampers are:

(*a*) Air plenum temperature control by mixing outside air and return air.

(*b*) Space temperature control by mixing warm air and cool air.

(*c*) Space temperature control by varying the flow of cool air.

(3) Examples of the use of 2-position dampers are:

(*a*) Closing outside-air dampers or building-exhaust dampers when fans are stopped.

(*b*) Isolating sections of ductwork for smoke-control purposes.

(4) Dampers are classified by the action of their blades, which connect to a common shaft that is rotated to open or to close the damper. Opposed blade dampers provide better flow characteristic in throttling applications. A throttling application is one where the damper is installed in series with the path of flow and the damper is used to add pressure drop to reduce air flow. Parallel blade dampers are used to provide better flow characteristics in mixing applications. A mixing application is one where more than one flow path exists in parallel. Usually, two or more dampers are installed in parallel to each other and the dampers divert flow rather than increase total system pressure drop.

(5) The control action of dampers (NC or NO) depends on the direction of their blade rotation caused by the spring-return stroke of an actuator connected to the damper's drive shaft, when the control signal or power is removed.

(6) When a control-system application requires that a damper be open prior to the start of a fan, an adjustable switch is connected to the damper; this device is called an

end switch or limit switch. The end switch operates a set of contacts in the fan-starter control circuit when the damper is fully open, to allow the fan to start; the end switch opens the circuit to prevent the fan from continuing to operate if the damper begins to close.

c. Actuators.

(1) Actuators are used to operate valves and dampers. Pneumatic actuators are powered by air pressure, and are controlled directly by a pneumatic control signal and indirectly by an electric or electronic signal. An electro-pneumatic device converts an electric or electronic signal to a pneumatic signal to stroke the actuator. Electric and electronic actuators are electrically powered and are controlled directly from an electric or electronic signal to stroke the actuator.

(2) Modulating control of actuators requires either the use of a 4 to 20 milliampere control signal directly to an electronic actuator or the conversion of the signal to a pneumatic control signal of 3 to 15 psig. The pneumatic signal can be directly or inversely proportional to the electronic signal. The signal conversion values are shown in figure 2-2.

(3) Two-position control of electric actuators requires the closing and opening of a contact to operate an electric actuator. Two-position control of pneumatic actuators requires an electric/pneumatic device to pass 20 psig main air to the actuator, or to exhaust air from the actuator.

(4) Sequencing occurs when actuators are modulated from a common signal by using a portion of the 4 to 20 milliampere signal or the converted 3 to 15 psig signal. The actuator stroke is adjusted to move its connected valve or damper from fully-closed to fully-open over the assigned portion of the common control signal. Deadbands between the movement of valves and dampers are achieved by assigning a portion of the common control signal as a deadband. Each actuator is adjusted so that its full stroke occurs on either side of the deadband limits outside of the deadband. Examples of the use of sequencing with a deadband are:

(a) Sequencing of heating and cooling with a deadband between heating and cooling.

(b) Sequencing of heating and outside ventilation air beyond the required minimum quantity with a deadband between heating and increased ventilation.

(5) Actuators are modulated in parallel by assigning the identical portion of the control signal to each actuator for its full stroke. Modulation in parallel occurs in air-stream mixing applications such as:

(a) Modulation of outside-air, return-air and relief-air dampers for free cooling.

(b) Modulation of multizone hot-deck and cold-deck dampers in parallel.

d. Current-to-pneumatic transducers. The modulating device for converting a current-control signal to a pneumatic-control signal is a current-to-pneumatic transducer (IP). A 20-psig main air supply to the IP is the source that develops a 3- to 15-psig output signal in a

scaled relationship to a 4- to 20-milliampere input signal.

e. Solenoid-operated pneumatic valves. The 2-position device for converting an electric-contact closure signal to a pneumatic signal is the solenoid-operated pneumatic valve (EP). The EP is a 3-way valve that connects the normally-closed and common ports when the solenoid coil is energized and connects the normally-open and common ports when the solenoid coil is de-energized. The EP is used to switch 20-psig main air to the actuators and to exhaust air from the actuators.

f. Positive Positioners.

(1) All modulating-control applications of pneumatic actuators require that the actuator be equipped with a positive positioner (PP). A main-air supply is the source of its operating power. The device throttles main air as required to stroke the actuator to the position dictated by the pneumatic control signal. However, the positive positioner can exert pressure higher than that of the pneumatic-control signal and thus can maintain the required position against the opposing force of the HVAC system pressure. Piping-system pressures tend to compress the air in the diaphragm chamber of the valve actuator. The compression causes a shift in the actual operating ranges of the valves. The positive positioner has an adjustable pneumatic-signal start point for the stroke of the actuator and an adjustable pressure span for the full stroke of the actuator. The stroke is proportional to the pneumatic control signal.

(2) Simultaneous heating and cooling can occur when pneumatic actuators are used, even though the spring-operating ranges are selected without an overlap. The results of this phenomenon are shown in figure 2093. Because of this phenomenon, sequencing applications for HVAC systems must have positive positioners on pneumatic valves and damper actuators, to maintain deadbands between actuator operating ranges. A control system with positive positioners is illustrated in figure 2094. When sequencing actuators from a common control signal, the simultaneous use of heating and cooling can accidentally occur if:

(a) Heating and cooling valve operating ranges overlap.

(b) Heating valve and ventilation damper operating ranges overlap.

(c) Heating valve and cooling air damper operating ranges overlap.

g. The choice between pneumatic and electric actuators. All terminal-unit control systems will have electric or electronic actuators. For all other control-system applications, the designer will make an estimate of the total cost of actuators required for all control systems in the project. The designer will take into account the cost of multiple actuators on large dampers and the cost of larger actuators required for higher torques to operate large valves. The total installed-cost estimate of pneumatic actuators will include:

(1) The actuators.

(2) The IPs.

(3) Tubing.

(4) Local indicators.

(5) The cost of the compressed-air system.

The total installed-cost estimate of electric actuators will include consideration of:

(1) The actuators.

(2) Wiring.

(3) Loop-driving circuits as explained in this manual.

h. Existing compressed-air source. If sufficient air is available from an existing temperature-control compressed-air system, it may be used as the air source for additional control systems.

i. Life-cycle cost. After the installed-cost estimates are prepared, a life-cycle cost estimate will determine the choice between pneumatic and electric actuators.

j. Sequencing actuators. The actuators that control valves and dampers are sequenced when HVAC applications require that the process variables be sensed at a common location and controlled from a common modulating signal. The objective of sequencing is to avoid energy waste by preventing the following opposing processes from acting simultaneously:

(1) Heating and cooling.

(2) Humidification and dehumidification.

k. Design requirement in regard to actuator-sequencing ranges. The designer will show the actuator-sequencing ranges in the equipment schedule when standard control signals apply.

(1) Pneumatic actuators are sequenced by connecting the signal input connections of the actuators' positive positioners to the same pneumatic control signal and adjusting the positioners' starting points and spans to achieve the required sequence. For example, two valves can be operated in sequence if their positive-positioner spans are set at 4 psig and their starting points are set at 3 psig and 9 psig respectively. This results in ranges of valve full-stroke operation of 3 to 7 psig and 9 to 13 psig, with a 2-psig deadband between the ranges of operation.

(2) Electric actuators have starting points and span adjustments similar to those of the pneumatic actuator's positive positioner. In this case, the starting points and spans are adjusted in milliampere values. When electric actuators are sequenced, the modulating-control circuit will be designed within a 600-ohm limitation.

l. Multiple actuators connected to the same control damper. When the operating-torque requirement for an HVAC-system damper exceeds the output torque of a single actuator, additional actuators are connected together to operate in parallel to control the damper. The designer is not required to show multiple actuators connected to the same damper on the schematic. The vendor has the information necessary in the contract specification to apply multiple actuators when required.

m. Design of modulating-control circuits within a 600-ohm circuit-impedance limitation.

(1) The output of an HVAC-system controller is

connected in series to actuators external to the HVAC control panel, and also to other devices in the HVAC control panel in a direct-current series circuit. The number of devices varies with the complexity of the control sequence, and the impedance of each connected device is additive as a resistance in the circuit. The amount of output-circuit impedance that a controller will tolerate is product-specific. The limitation of 600 ohms in the output-circuit design is needed to permit the controllers of several manufacturers to function in the same circuit. The limitation permits standardization in the design and permits substitution of one manufacturer's controller for that of another during maintenance of the system.

(2) If a modulating-control circuit is designed to use electric or electronic actuators, the impedance can exceed the 600 ohm limitation if:

(a) Multiple actuators are required for the same damper.

(b) More than one damper is modulated from the same control signal, such as in the case of modulating outside-air, return-air, and relief-air dampers.

(c) Multiple control-system devices located within the HVAC control panel are necessary to achieve the sequence of control.

(3) Many of the control-system devices typically add 250 ohms impedance to a series circuit. This 250-ohm impedance value comes from a dropping resistor in the device that is used to convert the 4- to 20-milliampere current signal at 24 volts dc to a 1- to 5-volt signal used by the device's internal circuitry.

(4) Figure 2-5 shows methods for designing circuits within the 600-ohm limitation. The figure shows the following examples:

(a) The limitation exceeded by connecting 750 ohms in series.

(b) Limiting the control-circuit connection to a single actuator.

(c) The circuit designed within the limitation by the use of an additional control-circuit device.

(5) In the first example, shown in the upper part of the figure 2-5, control devices 1, 2, and 3 can be actuators or devices in the HVAC control panel. In the second example, the controller is connected to actuator 1, and actuator 2 is operated by an auxiliary-actuator-driver (AAD) circuit on actuator 1; actuator 2 can operate another actuator by its ADD. In the third example, the same control devices are connected to a loop driver (LD). Control device 1 and the loop driver are connected to the controller. The modulating circuit from the controller is limited to 500 ohms, consisting of 250 ohms for control device 1 and 250 ohms for the input to LD. Control devices 2 and 3 add a total of 500 ohms to the output circuit of LD. The output signal of LD varies in a 1-to-I ratio with its input signal.

(6) Some of the control devices necessary to implement the control sequence have an input impedance of 250 ohms, and their output circuits can accept from 800 ohms to 1000 ohms of impedance. The amount of allow-

able impedance in their output circuits is product-specific. Any control device whose modulating-control output circuit has greater impedance-loading capability than the impedance of its modulating-control input circuit can function as a loop driver. In addition to performing a specific control-sequence function. This output-driving capability is found in most modulating-control devices.

(7) When the control system requires more than one damper with electric or electronic actuators to be modulated by a control circuit, the designer will show the signal (on the schematic) connected to one of the damper actuators. The AAD circuit of that actuator will be shown as connected to drive a separate actuator on another damper, which, in turn, can drive another actuator on still another damper.

(8) When a modulating-control circuit must drive multiple panel-mounted control devices, the designer will show on the schematic:

(a) Not more than 2 devices (such as IPs) connected to that circuit, unless one of the devices is a control device that accepts a modulating input signal and produces a modulating output signal.

(b) Not more than 2 panel-mounted control devices connected to the modulating output of a panel-mounted control device.

(9) The schematic is not intended to show the physical connections to the devices, but rather to show the relationship of the necessary control devices in the control loop.

n. *Transmitters.* Variables such as temperature, pressure, and relative humidity are sensed by means of elements that are connected to the control loops via transmitters. The output signal of the transmitter is the standard 4 to 20 milliamperes dc signal, which is factory-calibrated for zero point and span relative to the input resistance value of the sensing element. The transmitters are 2-wire, loop-powered (i.e., powered by the control-panel power supply) devices that connect in a series circuit with the controller input. The impedance limitation of the circuit in which the transmitter can function is product-specific. A typical value is 700 ohms at 24 volts dc.

o. *Single-loop digital controller.*

(1) A standard controller, known as a single-loop controller, will be used for all control-system applications except those required for the control of HVAC-system terminal units. In all applications where it is used, the controller will be mounted in a HVAC control panel. The controller-mounting dimensions will conform to a standard panel cutout requirement. The controller will be used for the following applications:

(a) As a controller for maintaining temperature, relative-humidity, static-pressure, and/or airflow setpoints.

(b) As an economizer-mode switchover controller that determines whether outside air is available for cooling.

(c) As an outside-air-temperature controller for scheduling hydronic-heating supply temperature and for starting and stopping pumps.

(2) The controller will be a microprocessor-based

device with manually-configurable control features resident in solid-state electronic-memory components. Manual access to the features of the controller will be through a keypad and an alphanumeric indicator on the face of the controller. The controller will have standard features that will allow it to serve all functions prescribed in its application. Standard features will allow the replacement of any controller by a spare not necessarily of the same manufacturer.

(3) The single-loop digital controller will have the following inputs and outputs:

(a) A process-variable analog input (PV).

(b) A remote-setpoint analog input for control-point adjustment (CPA).

(c) An analog output (OUT).

(d) A process-variable-actuated contact closure output (PV contact).

(e) A contact output that responds to the difference between PV and CPA analog inputs (DEV contact).

(4) Some controller features are configurable by manual input, and others are selectable by setting switches or jumper wires. The configuration methods vary with the specific manufacturer and model. The controller will have the selection of features for its inputs and outputs as shown in table 2-1.

Table 2-1
Controller Features

Input	Output	Feature
PV		Scalable to the range of the input transmitter.
CPA		Adjustable bias of setpoint relative to the PV input range.
CPA		Adjustable ratio of setpoint relative to the PV input range.
CPA		High and low limits of setpoint adjustment.
	OUT	Selection of direct-acting or reverse-acting.
	OUT	Adjustable high and low limits.
	OUT	Adjustable bias (Manual reset).
	OUT	Selection of manual or automatic control.
	OUT	Selection of proportional (P), proportional plus integral (PI), and proportional plus integral plus derivative control modes (PID).
	OUT	Anti-reset windup.
	OUT	Selection of manual tuning or self tuning.
	OUT	Manual reset feature for use when the controller is configured from proportional mode only and is manually tuned.
	PV Contact	Adjustable contact setpoint.
	PV Contact	Adjustable hysteresis or deadband.
	DEV Contact	Adjustable contact setpoint.
	DEV Contact	Adjustable hysteresis or deadband.

(5) The output control modes that can be used in combination are:

(a) Proportional mode, which varies the output proportionally to the error between the PV input value and the controller setpoint.

(b) Integral mode, which modifies the output signal as a time-related function of the error between the PV input value and the controller setpoint.

(c) Derivative mode, which modifies the output signal as function of the rate of change of the error between the PV input value and the controller setpoint.

(6) Each of these control modes has an assignable constant, which is adjusted in the process of tuning the controller.

(7) The integral mode will have a feature that automatically stops the integration of the error signal when the controller output signal reaches its minimum or maximum value. This feature is known as anti-reset windup. If the process being controlled does not respond to the controller output for a period of time (such as an overnight shutdown), continuing the integration of the error signal during that period would result in the controller failing to respond to control the process immediately on startup. Without the anti-reset windup feature, the controller would reverse the integration process on startup, but the reversal would require a time period equal to the time period of the integration during shutdown.

(8) The controller will have the following selectable modulating-control functions:

(a) Self tuning of control-mode constants.

(b) Manual tuning of control-mode constants.

(9) Self tuning allows the controller to select the optimal combination of proportional, integral, and derivative control-mode constants. The controller continues to use these selected constants until the self-tuning control function is again selected. Applications where self tuning is used are as follows:

(a) Mixed-air temperature control.

(b) Heating-coil temperature control for multizone hot-deck and dual-duct hot-duct applications.

(c) Modulating-value and modulating-damper preheat-coil control.

(d) Cooling-coil discharge-temperature control for multizone cold-deck, dual-duct cold-duct, and VAV-system discharge temperature.

(e) Relative-humidity control.

(f) Supply-duct static-pressure control.

(g) Return-fan volume control.

(h) Hydronic heating supply-temperature control.

(i) Hydronic-heating space-temperature control.

(10) If integral and derivative control modes are not appropriate for an application, the controller is manually tuned for proportional-mode control, and the integral and derivative mode constants are set to zero. Applications where manual tuning is used are as follows:

(a) Relative-humidity high-limit control.

(b) Outdoor-air scheduling of hydronic-heating supply temperatures.

(c) Space-temperature control of single-zone HVAC units and heating and ventilating units.

(11) When the single-loop digital controller is manually tuned to operate as a temperature controller in the proportional mode, the proportional-band setting is determined by the use of equation 2-1.

$$PB = (T \times 100) / T_s \quad (\text{eq. 2-1})$$

Where:

P_B = Proportional-band constant (percent)

T = Portion of the transmitter span required for full-scale controller output change (degrees F)

T_s = Temperature span of transmitter (degrees F).

(12) If the controller output is to change from 4- to -20 milliamperes over the range of 0 to 60 degrees F and the transmitter range is in the range of minus 30 to plus 130 degrees F (a span of 160 degrees F), the use of equation 2-1 would result in:

$$PB = 37.5 \text{ percent.}$$

(13) When a single-loop controller is configured for proportional control mode only, the output of the controller must be set to match the value required for the application when the PV input value coincides with the controller setpoint. This is accomplished by configuring the manual reset setting as a percent of controller output. The effect of this configuration parameter is to shift the controller output throttling range with respect to the controller setpoint. As an example, refer to figure 2-6 which shows the setpoint relative to the controller throttling range for manual reset settings of 25, 50 and 75 percent for a direct-acting controller.

(14) When used as an economizer-switching controller, the functions of the controller inputs and outputs will be as follows:

(a) A return-air temperature transmitter connected to the PV input.

(b) An outside-air temperature transmitter connected to the CPA input.

(c) An output contact configured as PV and acting as a switch.

(d) An output contact configured as DEV and acting as a switch.

(15) As the outside-air temperature changes, the potential for using outside air for cooling is affected. When the outside-air temperature is lower by a specified number of degrees than the return-air temperature, outside air can be used for cooling; when the reverse is true, outside air must be at minimum quantity. The PV contact setpoint prevents the use of outside air beyond minimum quantity until the return-air temperature rises to its set-point. When the return-air temperature rises to the PV contact setpoint, the HVAC system is no longer experiencing a heating load. The DEV contact setpoint allows the use of outside air until the outside-air temperature approaches the return-air temperature. The DEV contact then puts the dampers under control of a minimum-position switch. A minimum-position switch is a device whose control output is manually modulated to an actuator that then remains fixed until reset manually. Both conditions must be met PV and

DEV contacts closed) for the use of outside air beyond minimum quantity.

p. Function Modules.

(1) There are control functions required with less frequency in HVAC control applications than those included in the prescribed version of the single-loop controller. Control devices to perform specific control functions not available in the single-loop digital controller are called function modules in this manual. Function modules will be located in the HVAC control panel, except as noted. Function modules accept contact, analog, or gradual manual adjustment input signals to provide:

- (a) Signal selection,
- (b) Signal inverting,
- (c) Contact transfer output from analog signal input,
- (d) Contact transfer output from the comparison of two analog input signals, and
- (e) Generation of constant analog-output signals.

(2) A minimum-position switch is a manually-adjustable modulating output device used to hold an outside-air damper open to admit minimum ventilation air. This same device is used as a temperature-setpoint selector. In this application, it allows manual adjustment of the CPA input signal to a single-loop digital controller. In the case of certain single-zone HVAC systems, this device is wall-mounted and accessible to the occupant for adjustment of the space-temperature controller setpoint.

(3) A signal inverter is a modulating-input and modulating-output device used to reverse the direction of its input. The signal reversal is required when spring-return position of a valve or damper actuator has been chosen to operate with a direct-acting signal, and when an actuator with which it must be sequenced has been chosen to operate with a reverse-acting signal. For example, a chilled-water coil is used for dehumidification and cooling. The chilled-water-coil valve is chosen as NC because it is to be sequenced with a NO heating-coil valve, and is to close when the control signal is removed during fan shutdown and during the unoccupied mode. The direct-acting temperature-control signal is correct for this combination. The humidifier control valve is also chosen as NC because it also is to close when the control signal is removed on fan shutdown and during the unoccupied mode. The humidity-control signal must be reverse-acting when it operates the humidifier valve, and must be direct-acting when it operates the cooling-coil valve. A signal inverter is used to reverse the signal direction of the humidity controller signal to the cooling-coil valve.

(4) A signal selector is a device with multiple modulating inputs and a modulating output. This device is used to select the highest or the lowest of its input signals as its output.

(5) A sequencer is a modulating-input and time-delayed contact-output device which operates its outputs in sequence and is used in applications that require the operation of stages in refrigeration control from a modulating-control signal. The time delay prevents all

stages of refrigeration from starting simultaneously when the HVAC system starts. The contact opens instantaneously on power failure (or on signal failure) to the sequencer. This instantaneous action prevents all stages of refrigeration from starting simultaneously if electric power to the control system is interrupted momentarily.

(6) A loop-driver module is used where required to allow modulating-control circuits to be designed within a 600-ohm impedance limitation. A loop-driver module can be any modulating-input or modulating-output device used for this purpose alone or while performing an additional control loop function. Signal selectors and signal invertors strategically located in control loops often perform such dual service.

q. Relays, including time-delay relays. All relays, including time-delay relays, will be 2-pole, double-throw devices; they are used for control-system interlocking functions and will be located in the system's HVAC control panel.

r. Time clocks.

(1) A time clock will be used to control the timing of the modes of operation of an HVAC control system when the control system is not interfaced with EMCS. When a time clock is used, it will be located in a HVAC control panel. The modes of operation are occupied, unoccupied and ventilation delay.

(2) The time clock will be a device that accepts a time schedule by manual input through a keypad and an alphanumeric display. The time clock features will be:

- (a) Two independently-time-controlled contacts.
- (b) A program of 4 "on" events and 4 "off" events for each contact.
- (c) 365-day schedule.
- (d) Twelve selectable holidays.
- (e) Standard-time and daylight-time adjustments.
- (f) Timed override of programs.
- (g) Battery backup of memory.

(3) When used to time the modes of operation of air handling systems, one contact of the clock will be used for occupied and unoccupied timing; the second contact will be used for ventilation-delay mode timing. For other applications, the contacts may be used as convention to the design.

2-4. Control loop

A control loop performs three distinct functions: sensing of a variable as the input to a controller; decision-making or control based on the valve of the input; and output or actuation as a result of control. Figure 2-7 illustrates a simple control loop. The input signal is a continuous analog of the process, and the controller either continuously sees the input or continually scans it. The controller changes its output as required by changes in its input.

2-5. Open control loop

When a control loop senses a variable, makes a control decision, and sends an output signal to a control device

without receiving input information related to the results of its control action, the control loop is said to be an open loop. There are some open-loop control applications used in HVAC control, such as:

- (1) Operation of pumps above or below a certain outside temperature.
- (2) Automatic stopping of HVAC systems based on outside-air temperature.
- (3) Scheduling of hydronic-heating supply temperatures based on outside temperatures.
- (4) Timing and time-delay operations. Figure 2-8 illustrates an open control loop.

2-6. Closed control loop

When the controller changes its output decision based on updated input information, the control loop is said to be a closed loop. Most of the control loops used in HVAC control are closed loops. Control of coil-air discharge temperatures is an example. The transmitter, connected to a temperature-sensing element in the air stream passing through the coil, signals the temperature controller; the controller makes a decision as to whether to open or close the valve that allows water to flow through the coil; and an actuator operates the valve. The feedback in this example is the continuous input to the controller of a changing temperature signal from the coil-air discharge temperature sensor and transmitter. The transmitter continuously updates the controller on temperature information from the sensor, and the controller modifies its output to control the valve. See figure 2-9 for an example of a closed control loop.

2-7. Application of open-loop control and closed-loop control to HVAC Systems

a. Open loops and closed loops in combination. Open loops and closed loops are used in combinations in some HVAC control-system applications. A perimeter hydronic-heating system may have open-loop components to start and stop the pump and to schedule the supply-water temperature based on outside-air temperature. At the same time, it may have a closed loop for the control of the supply-water temperature.

b. Closed loops in combination. There are some HVAC control applications that use two simultaneously-acting, closed control loops to actuate the same device. An example, as shown in figure 2-10, is control of a duct humidifier. A space relative-humidity transmitter is the primary input to a relative-humidity controller for the humidifier valve in a closed loop (loop 1). A duct-mounted humidity transmitter downstream of the humidifier signals a high-limit relative-humidity controller, which provides a high-limit closed-loop control function (loop 2), by overriding the primary controller loop 1 to shut off humidification by closing the valve if the relative humidity of the air stream rises to the loop-2 relative-humidity high-limit setting.

2-8. Typical control modes

a. Two-position control.

- (1) Some HVAC equipment can be turned on and off

as a method of temperature control. This type of HVAC equipment is not applied where temperature control between close limits is required.

(2) When a thermostat or other control device cycles equipment to maintain its setpoint the control mode is called two-position control. A thermostat used for two-position control opens and closes contacts for control rather than providing a modulating output signal. The contacts either open or close when the temperature is at the thermostat setpoint. The state of the contact reverses when the temperature changes in the proper direction. Such thermostat contacts usually either open on a temperature rise (in a heating application), or close on a temperature rise (in a cooling application). The temperature at which this happens depends on the switch temperature differential (hysteresis).

(3) An example of two-position control is unit-heater control, in which a _{space} thermostat turns on a unit heater when the space temperature drops to 65 degrees F and turns it off when the space temperature rises to 67 degrees F. The thermostat is said to have a differential of 2 degrees F and a setpoint of 65 degrees F. This type of control can result in a slight undershoot below the lower end of the differential, and a slight overshoot above the higher end of the differential.

(4) The thermostat may turn off the unit at 67 degrees F, but the heating load may decrease due to increasing outside-air temperatures. In this event, water circulating through the unit coil, which will then be acting as a radiator with the fan off, may raise the temperature in the space slightly above 67 degrees F as an apparent overshoot. Even though the unit turns on when the space temperature drops to 65 degrees F, the space temperature may fall slightly below 65 degrees F after the unit starts. This depends on the heating capacity of the unit. If the heating load decreases, the temperature may subsequently rise to 66 degrees F, and stay at that temperature for a considerable time, while the fan continues to run. A similar situation can happen after the unit heater shuts off at 67 degrees F and the space temperature drops to 66 degrees F. Consequently, the space temperature may be 66 degrees F with the unit heater fan either running or stopped. A graphic representation of two-position control is shown in figure 2-11.

b. Modulating Control. A simple control loop is shown in figure 2-12 as it would be applied to heat outside-air for ventilation using a pneumatic-valve actuator rather than an electric- or electronic-valve actuator. The controller operates an IF in response to the signal of the temperature-sensing element in the air duct, downstream of the coil, via a transmitter. The IP pneumatic output signal modulates the positioner on the pneumatic valve actuator. The positive-positioner output throttles main air to the actuator, which moves the valve stem. This example is used to explain two modes of modulating control that are applicable to the control of valves, dampers, inlet vanes, and other devices. The modes applicable to most HVAC-control applications are:

- (1) Proportional mode (P).

(2) Proportional plus integral mode (PI).

c. *Proportional mode (P)*. The most common control mode in HVAC control is proportional mode.

(1) Proportional mode is used for the following applications:

(a) As a method of scaling an outside-air temperature signal to schedule water temperatures for heating.

(b) As a method of space-temperature control for single-zone air-handling units.

(c) As a method of controlling terminal units that can be modulated.

(2) Figure 2-13 shows the kind of control that would be expected if the controller in figure 2-12 were configured for the proportional-control mode. The controller modulates its output signal in proportion to variations of the input signal. For example, the controller, operating through the IP, sends a 3-psig air signal to the normally-open preheat-coil valve when the discharge temperature is 43 degrees F, and it sends a 15-psig signal when the discharge temperature is 47 degrees F. The 3-psig signal completely opens the valve to heating, and the 15-psig signal completely closes the valve to heating. The controller/IP combination has a proportional sensitivity of 3 psi per degree F, and throttles the valve over a range of 4 degrees F. The setpoint of the controller is 45 degrees F, but the temperature at which it is controlling is somewhere between 43 degrees F and 47 degrees F. It takes a 4-degree F change in controller-output signal for the valve to go from full heating to no heating.

(3) On a fall in outside-air temperature, the heating load increases. The resultant drop in temperature at the sensor causes the transmitter to signal the controller to lower its output to the IP transducer. The IP transducer lowers the control air pressure to the normally open valve, allowing more heating medium to pass through the coil, thereby returning the discharge temperature almost to the temperature maintained before the fall in outside temperature. Increasing the controller's sensitivity would shrink the full heating/no heating temperature range; decreasing its sensitivity would increase that range.

(4) The phenomenon that prevents the proportional-control mode from achieving its control point exactly at setpoint is called "offset due to loan". This occurs when an equilibrium is reached between HVAC-system output and the load imposed on the HVAC system. When this equilibrium occurs, the discharge temperature does not change. This means that the proportional-mode controller does not change its output and cause a change in the HVAC-system output. Conversely, without the change in HVAC-system output to drive the temperatures toward the controller setpoint, the controller output does not change. Therefore, at these equilibrium points, the controls do not bring the system back to setpoint.

(5) Figure 2-13 shows the relationship between coil discharge temperature and controller/IP output in response to changes in outside-air temperature. Except between point A and B the controller/IP output is proportional to

the discharge air temperature. Between points A and B, the coil discharge air temperature is the same as the outside-air temperature. At points A and B, with a coil discharge temperature of 47 degrees F, the output is 15 pounds and the valve is closed. At the fifth hour when the discharge temperature is at the 45 degrees F setpoint the controller/IP output is 9 pounds and the valve is half open. If the valve is closed at 47 degrees F outside-air temperature and is half open with a twenty-degree pickup at 25 degrees F outside-air temperature, then by extrapolation the valve is fully open at outside-air temperatures of 3 degrees F and below. As soon as the air temperature leaving the coil, the incoming outside-air temperature, and the heating action of the coil reach an equilibrium, the valve remains at a given position until the equilibrium is disturbed by changes in the outside-air temperature.

(6) For a given load on the system, there is some optimal proportional-sensitivity adjustment at which the controller will be in stable control and close to the setpoint. In some HVAC control applications, proportional control may function quite well with a high-sensitivity adjustment. A high-sensitivity adjustment results in a narrow range of temperature drift from setpoint while the controller changes its output from full output to minimum output. Too high a sensitivity adjustment causes the control point to continuously overshoot and undershoot the setpoint. In other control applications, stable control may not be achievable with a high-sensitivity adjustment. A low-sensitivity adjustment results in a wide range of temperature drift from setpoint while the controller changes its output from full output to minimum output, but control is usually more stable. After the controller sensitivity has been adjusted, changing conditions of load due to seasonal and other factors tend to make the adjustment less than optimal. This phenomenon is a function of HVAC-system capacity and HVAC-system response to load changes. The sensitivity of a proportional controller to process variable changes is called proportional gain.

(7) As long as the proportional controller is controlling in a stable fashion, at varying load conditions, at some control point near the setpoint and the proportional-gain setting is optimum, the controller has achieved the most precise control of which it is capable.

d. *Proportional plus integral mode (PI)*.

(1) Many control applications require a controller that can eliminate offset due to load and can control very close to setpoint. To achieve closer control than is available from the proportional-control mode, some automatic adjustment has to be made to the controller output to change the actuator position without changing the setpoint or the proportional-gain setting. The method used to adjust the controller output for changes in load is called "integral mode". Integral mode adds a gain component algebraically to the controller output. This component is time-proportional to the difference between the setpoint and the stable control point produced by the controller's proportional gain. This difference is caused by the offset

due to load and is called steady-state error, which is the error between control point and setpoint when a balance between the load on the system versus the system capacity output and controller output is established. Steady-state error differs from the transitory error between set-point and control point due to an upset in the process, such as a changing load or a step change in setpoint.

(2) The integral mode adds a component of output to the output of the controller that is produced by the controller's proportional gain. The size of the component is determined by the integral gain multiplied by the error. As the error decreases, the size of the component integrated to the output signal also decreases, and becomes zero when the controller is controlling at the set-point. This added component of output causes the valve-actuator-stroke position to change. This change in valve capacity resulting from the change in the actuator-stroke position upsets equilibrium or prevents equilibrium from occurring until the control point reaches setpoint. This action causes two things to happen. The resulting temperature change due to the change in valve-actuator-stroke position causes the proportional gain to change its component of output signal at a magnitude proportional to the change in the temperature being sensed. While this is happening, the error changes because the control point is closer to setpoint, and this in turn causes the integral gain to make a change in the magnitude of its component of the output signal due to the changing value of the magnitude of the error between control point and setpoint. There will be no further change in the proportional-mode or integral-mode output components when the steady-state error is zero. Because of the combined action of both of these control modes, the controller can reduce the offset to zero, or nearly zero, and can establish a steady-state equilibrium of HVAC system control at a value very near setpoint. This type of control is called Proportional-Integral (PI) control.

(3) See figure 2-14 for an illustration of proportional plus integral control modes. The upper graph of the figure is identical to the upper graph of figure 2-13. The lower and middle graphs provide a comparison of the proportional-mode controller output and resulting coil-air discharge temperatures (light lines) versus those of a PI-mode controller (dark lines). In the beginning of the middle graph the integral-mode component is positive and is added to the proportional mode component. This additional pressure closes the normally-open valve where the outside-air temperature reaches setpoint 45 degrees F, instead of at point A, at which the coil discharge-air temperature is 45 degrees F plus half the controller throttling range or 47 degrees F (45 \$ 4/2). The 47 degrees F temperature would have occurred with proportional control, at point A. Similarly, when the outside-air temperature falls to 47 degrees F. the integral-mode component prevents the valve from opening until the outside-air temperature falls below 45 degrees F. The proportional only mode controller would have begun to open the valve at 47 degrees F outside-air temperature at point B. From the time the valve

begins to open at the outside-air temperature of 45 degrees F until the fifth hour when the outside-air temperature is 25 degrees F the integral-mode component of the controller output signal becomes smaller until at the fifth hour the integral-mode component becomes zero. This additional pressure on the normally-open valve allows the coil air discharge temperature to remain at the 45 degrees F setpoint instead of controlling between 47 and 45 degrees F when the outside-air temperature is between 45 and 25 degrees F as would have occurred with proportional only control. Similarly, when the outside-air temperature falls below 25 degrees F, the integral-mode component is subtracted from the proportional-mode component of the controller output signal to open the valve enough to keep the discharge-air temperature at 45 degrees F rather than at 43 degrees F as would have occurred with proportional-mode control.

e. *Effects of rapid load changes*. The rate of change of load imposed on the HVAC system by the process affects how well the controller will perform its task of controlling at setpoint. The temperature of the outside air changes relatively slowly, and the temperature conditions inside also require some time to change. Inside conditions change as a function of air-temperature changes made by the HVAC system, which warm up or cool down masses of material within the building. Inside conditions also change as functions of lighting load and occupancy. Because of these relatively slow rates of change, most of the HVAC processes that require gradual controller output changes can be controlled quite well with proportional plus integral (Pi) control modes. Except for lighting loads on the HVAC system, these variable changes are relatively slow compared to the rates of change of variables that affect some non-HVAC processes. Lighting loads are sometimes imposed on the HVAC system quickly. This is an example of a step change in the process variable. The combined actions of proportional and integral modes are not always adequate to control rapidly-changing variables.

f. *Proportional-integral-derivative (PID) mode*.

(1) Some processes require a controller that can respond to rapidly-changing process variables. One answer to control of rapidly-changing processes has been the addition of another control mode called derivative mode. When this control mode is added to proportional-integral control, the combination is known as proportional-integral-derivative (PID) control mode. The PID control mode adds a component algebraically to the output signal; this component is proportional to the rate of change of the error between the control point and setpoint. This automatic adjustment also affects the proportional and integral output components in a manner analogous to the way in which the integral component affects the proportional component. As the valve-actuator-stroke position changes, the temperature changes as a result of changing flow through the valve, and the rate of error-signal change between the control point and setpoint varies as the control point comes closer to setpoint.

(2) There are a few HVAC-control applications that are difficult for either P-mode or PI-mode control because of the fast rates of change of the process variables. One such application is the control of tankless heating converters, such as might be found in some domestic hot-water-heating applications. The I-mode component of Pi-mode takes care of the varying range of offsets due to loads that occur in domestic hot-water heating applications. For example, high-rise residential buildings have morning and evening peak periods of demand for hot-water use. These peak-demand periods drive the domestic hot-water temperature to the low end of the offset range. Periods of relative nonoccupancy, such as late morning and early afternoon, drive the temperature to the high end of the offset range due to the minimal demand for domestic hot-water use. Periods of relative inactivity during occupancy, such as late evening and very early morning, require practically no domestic hot water. It is this period that defines the top end of the offset temperature range. The P-mode control alone does not control the water temperature very close to the controller setpoint in this kind of application. The addition of the I mode to the P mode makes the offset range much narrower than would occur with P mode alone. However, Pi modes alone cannot handle the unpredictable diversity of demand as the peak periods start and end. What happens during the period of light demand for hot-water use is that the turn-on of a shower or the startup of a dishwasher produces an upset in equilibrium that has a greater effect than the same event would have during a period of heavy demand. Periods of heavy demand tend to filter out some of the effect of a single turn-on.

(3) In the control-loop applications where manual tuning is prescribed, the proportional-mode constant is set as the result of a calculation. These applications cannot use the integral or derivative control modes. Self tuning is prescribed for these applications because finding the optimum settings manually is difficult and time-consuming. When controllers self-tune, these settings are automatically optimized, and an optimized derivative-mode setting is selected due to the controller's self-tune feature. The effects of adding the I and D modes to the P mode is illustrated in figure 2-15, which shows the results that would be expected with a step change in set-point. Step changes in setpoints rarely occur in HVAC control system applications. The illustration of the step change in setpoint is used to graphically explain the actions of P, I, and D modes.

2-9. Standard HVAC-system control loops

a. Standard HVAC-system control loops will be used for the design of HVAC-control systems. The standard HVAC-system control loops use the single-loop digital controller and additional components. These components are collectively called the control-loop logic. The logic varies with the loop requirements, and its purposes are to interface the loops with the operational-mode signals, to modify signals, and to interface with EMCS. The control-loop logic is implemented by the use of combinations of relays and function modules.

b. Relay coils are activated by occupied-unoccupied, ventilation-delay, safety-shutdown, EMCS-override, and other signals external to the HVAC-control system. The contacts of the relays interrupt analog signals of controllers and function modules, provide inputs to on/off control loops (such as starter circuits), and operate HVAC control-panel pilot lights.

c. All the relays, contacts, and function modules are defined for each loop. The relative physical locations of the relays and function modules will be assigned in the HVAC control panels.

d. Each of the standard HVAC control loops is described in this technical manual as the designer will show them on the contract drawings. Each control loop on the drawings will show the elements of the control loop, such as sensor-transmitters, controller, function modules, relay contacts, current-output to pneumatic signal converter (IP), and final actuator. The control loops will show all the field-mounted and panel-mounted devices for a standard loop. Each control loop will show function modules and relay contacts that are defined for the interfacing of analog control loops with on/off control loops.

2-10. Sizing and selection of control-system devices.

a. The designer will estimate the required motor horsepower of the HVAC control-system air compressor, to provide the proper requirements for incorporation into the electrical power design.

b. Control-system devices such as dampers and valves are sized on the basis of capacity requirements and allowable pressure drops and velocity ranges. The selection of the type of valve or damper is based on factors such as allowable leakage rates and available or practical size ranges.

c. The designer will analyze piping-circuit pressure drops and their effects on the system's pressure drop due to the control valves, based on criteria presented in this manual. The designer will calculate the required liquid-flow coefficients © for each valve and will show the C_v for each valve. The designer will make sure that pumps are selected to include the pressure drop through the total circuit, and will then show the pressure against which the valve must close.

d. The designer will size control dampers based on the criteria presented in this manual and will show the size of each damper.

e. Oversizing of control devices would result in systems in which it would be difficult or impossible to obtain satisfactory control-loop operation, regardless of the quality of the controller and components used. The designer must not assume that self-tuning controllers will compensate for oversizing of control devices. The I and D modes compensate for HVAC-system load variations and HVAC-system equilibrium upsets, but do not compensate for incorrect valve and damper sizing.

2-11. Sizing of the air-compressor motor

a. Calculation. The designer will estimate the required

air-compressor-motor size, using equation 2-2, in order to coordinate with the power circuit serving the air compressor.

Tr = (Qc × 100) / Qd (eq.2-2)

Where:

Tr = Air-compressor running time (percent).

Qc = Control-system air consumption in standard cubic inches per minute (scim).

Qd = Air compressor delivery in standard cubic inches per minute (scim).

b. Running-time criteria. The designer will use the following running-time criteria for sizing air-compressor motors:

(1) *New air compressors.* The running-time design criterion for new air compressors is that the running time will not exceed 33½ percent. This requires that, initially, the delivery capacity of the air compressor must be at least three times the estimated air consumption for the whole control system that it serves. The designer will count the number of each type of air-consuming device shown on the schematics and apply their characteristic consumption values to arrive at the consumption total. The designer will base the calculation on the air consumption for each device as shown in table 2-2.

(2) *Existing air compressors.* Control systems can be added to an existing air compressor until the running time reaches 50 percent.

Table 2-2 Air Consumption of Control Devices	
Device type	Air consumption (scim)
IP.....	435
Butterfly-valve actuator positive positioner or inlet-vane actuator positive positioner.....	865
Damper or valve positive positioner	10
EP	0

c. Application of air-consumption values to sizing of air-compressor motors. An example of the application of the values in table 2-2 is as follows:

5 IPs @ 435 scim each = 2,175 scim
15 valve and damper positioners @ 10 scim each 150 scim
2,325 scim

Therefore,

2,325 x 3 (for a running time) = 6,975 scim

A check of manufacturers' catalog shows that a 1-hp compressor delivers about 6,560 scim and that a 1½-hp compressor delivers about 8,900 scim. Thus, a 1-hp compressor for the indicated control system would run 35 percent of the time, while a 1½-hp compressor would run 26 percent of the time. On the basis of this estimate, a power circuit capable of serving a 1½ hp motor would provide adequate margin to compensate for variances in the air consumption of control devices selected by the control-system vendor.

2-12. Determination of control-valve flow coefficient (C_v).

a. The control valve flow coefficient (C_v) is a number representing the number of gallons of 60-degree F water that will flow through a valve with a 1 psi pressure drop. The designer will calculate and select the liquid-flow coefficient (C_v) of all modulating-control valves required for the design, and show the pressure against which the valve must close. The selection of the valve's C_v provides the guidelines for the vendor's selection of the valve's port size. The close-off pressure information gives the required criterion for sizing the actuators for the valve selected by the vendor.

b. A valve that is operated in a 2-position open and closed manner will be a line-size valve with the largest available C_v in order to reduce the pressure drop across the valve and the pumping horsepower required. This applies to dual-temperature-system changeover valves and dual-temperature fan-coil-unit 3-way valves.

c. The designer will select the C_v of the valve based on the maximum flow and the pressure drop for the valve. The selected control valve will be checked against manufacturer's catalogs to ensure that such a valve C_v is available in a product of the control-valve manufacturers.

d. To ensure good control characteristics, the pressure drop through the control valve at full flow must be greater than the pressure drop through the coil and piping circuit (without the control valve) between the point where the piping circuit connects to the supply and return mains. The pressure drop through the control valve will then be at least 50 percent of the total pressure drop through the circuit. The valve C_v must be specified accordingly. For liquid service, the vendor may supply a control valve with a plus 25 percent deviation from that specified. The designer must check to ensure that the pressure drop through the valve will be acceptable at both the specified C_v and at a C_v 25 percent greater than specified. As the C_v increases the pressure drop through the valve decreases. For steam service, the vendor must supply a control valve with a C_v not less than the value specified and not larger than the manufacturers next larger value.

2-13. Calculation of liquid-control-valve flow coefficient (C_v)

a. A physical phenomenon known as cavitation is a cause of valve failure. Cavitation is caused when the velocity through the valve creates an absolute pressure lower than the vaporization pressure of the liquid. To avoid cavitation, use equation 2-3 to determine the maximum allowable pressure drop through open valves.

Pm = Km (Pe - Pv) (eq. 2-3)

Where:

Pm = Maximum allowable pressure drop through the valve (psid).

Km = Valve pressure-recovery coefficient (use 0.45).

Pe = Absolute pressure entering the valve (psia) (by design calculations).

Pv = Absolute vapor pressure of the liquid (psia) (from steam tables).

For examples: If 200-degree-F water with an equivalent vapor pressure of 11 .53 psia is to flow through a valve with an inlet pressure of 20 psig (34.7 psia), the maximum allowable pressure drop through the valve, as a result of using equation 2-3, will be 10.43 psid.

b. The pressure drop through the control valve must be at least 50 percent of the total pressure drop, as full flow, through the circuit. Continuing with the above example, assume a coil with a flow of 50 gpm and a 4 psig drop through the coil, piping and fittings between the mains. The maximum allowable pressure drop to avoid cavitation was calculated to be 10.43 psid. An initial valve pressure drop selection of 6 psid will prevent cavitation and provide sufficient valve pressure for good control. The C_v can be calculated from:

$$C_v = \frac{Q}{[P/G]}^{1/2} \quad (\text{eq. 2-4})$$

Where:
C_v = Liquid-valve flow coefficient (gpm per psid)
Q = Gallons per minute (gpm).
P = Pressure drop through valve (psid).
G = Specific gravity of the liquid.

The specific gravity of water is 1. As the result of using equation 24, C_v = 20.41. If the designer specifies a of 20, the vendor can provide a valve with a C_v in the range of 20 to 25. If the vendor provides a valve with a C of 25, the pressure drop would be 4 psid as calculated by using equation 24. This valve selection would make the pressure drop through the valve exactly 50 percent of the drop through the total piping circuit. Knowing that a plus 25 percent deviation in valve C_v selection is allow-able, the designer could select a C_v which would result in a larger pressure drop through the control valve. With a C_v of 16, the valve pressure drop will be 9.76 psid as calculated by the use of equation 24. This is less than the maximum allowable valve pressure drop of 10.43 psid, and the circuit pressure drop would be 4 psid (coil and piping) plus 9.76 psid (valve) = 13.76 psid. A C_v of 16 would result in the pressure through the valve being 71 percent of the drop through the piping circuit. If the designer specifies a C_v of 16, the vendor can provide a valve with a C_v in the range of 16 to 20. Cavitation will not be a problem in this example if the water temperature used in 200 degrees F, or less. In most HVAC control-valve applications, water temperatures are less than 200 degrees F. When the hot-water temperature is scheduled from outside air, 200-degree-F water will occur only on design heating days. Also, cavitation should not be a problem in hydronic systems when expansion tank pressures are adjusted so that cavitation is not present at the pump inlet. Selection by the designer of a control valve C_v of 20 rather than a C_v of 16 would be technically acceptable according to the criteria of this TM, but would not be a good engineering practice. If the larger C_v is used as the basis of design, the contractor may provide a valve with a C_v of 25. A C_v of 25 may result in the valve pressure drop being less than 50 percent of the drop through the circuit. The basis of design

valve C_v is selected because of the drop expected through the basis of design coil and the piping system configuration shown by the designer. The coil provided by the contractor, field piping conditions and aging of the piping system are factors which could result in the installed valve being less than 50 percent of the drop through the coil when the contractor provides a valve with the largest C_v permissible.

c. Review of manufacturers' catalogs shows the ready availability of valves with C_v in the range of 16 to 25, as listed in table 2-3.

Table 2-3 Available Control Valves with C _v in the Range of 16 to 25		
Valve Type	Valve Size	C _v
Normally-open water valve	1-inch	18
Normally-open water valve	1¼ inch	22.2
Normally-open water valve	1¼ inch	17
Normally-open water valve	1¼ inch	16
Normally-open water valve	1½ inch	25
Normally-open water valve	1½ inch	20
Three-way valve	1-inch	18
Three-way valve	1-inch	18.1
Three-way valve	1¼ inch	16
Three-way valve	1¼ inch	17
Three-way valve	1½ inch	25
Three-way valve	1½ inch	21

At this point, the designer will check the line size of the piping circuit and check the piping size of the reducing fittings. A good choice for the designer would be to show the C_v at 16 and the maximum close-off pressure at 20 psig in this example because there are more control valves available in the range of 16 to 20 (a plus 25 percent deviation) than there are in the rage of 20 to 25 (a plus 25 percent deviation).

d. The C_v calculations for selecting a butterfly valve are identical to those for any valve except that the valve C_v is selected using the calculated C_v at a maximum of 70 degrees open when the valve is to be used in a modulating-control application. (The butterfly valve does not have a good modulating control characteristic curve between 70 degrees and 90 degrees open.)

e. When selecting control valves for liquid service other than water, the designer will take into account the specific gravity of the liquid. If the liquid has a specific gravity of 1.05, for the same gpm, the liquid flow will produce a 5 percent greater pressure drop through the valve.

2-14. Calculation of steam-control-valve flow coefficient (C_v)

a. Calculating and selecting the required C_v of a steam valve requires the designer to consider:

- (1) The saturated or superheated condition of the steam.
- (2) The inlet pressure at the valve.
- (3) The minimum required steam pressure entering the steam-condensing apparatus at peak heating load.

b. the designer will use equations that correct the liquid C_v for the compressibility of the steam. The designer will take into account in his calculations that the limiting factor of steam flow through a control valve is the flow that occurs at critical pressure drop, and will use an appropriate factor for calculating the critical pressure drop. The designer will calculate the critical pressure drop across the valve by using equation 2-5.

$$P_{cr} = K_m (P_e) \quad (\text{eq. 2-5})$$

Where:
P_{cr} = Critical pressure drop (psid).
K_m = Valve pressure-recovery coefficient (use 0.45)
P_e = Absolute pressure of the steam entering the valve (psia).

c. For steam-control-valve application using saturated steam at a pressure drop across the valve less than the critical pressure drop, the C_v will be calculated using equation 2-6.

$$C_v = \frac{Q}{2.11[(P_e + P_o) P]^{1/2}} \quad (\text{eq. 2-6})$$

Where:
C_v = Valve flow coefficient (gpm per psid).
Q = Pounds of steam per hour.
2.11 = Compressibility and conversion factor.
P_e = Absolute steam pressure entering the valve (psia).
P_o = Absolute pressure entering steam coil (psia).
P = Pressure drop through valve (psid).

d. When the drop across the valve will be at or greater than the critical pressure drop and the steam is saturated, the C_v will be calculated using equation 2-7.

$$C_v = \frac{Q}{1.74 P_e} \quad (\text{eq. 2-7})$$

Where:
C_v = Valve flow coefficient (gpm per psid).
Q = Pounds of steam per hour.
1.74 = Compressibility and conversion factor.
P_e = Absolute pressure of entering steam (psia).

e. For superheated steam applications where the drop across the valve is less than the critical pressure, the C_v will be calculated using equation 2-8.

$$C_v = \frac{Q (1 + 0.0007 T_{sh})}{2.11 [P + P_o] P^{1/2}} \quad (\text{eq. 2-8})$$

Where:
C_v = Valve flow coefficient (gpm per psid).
Q = Pounds of steam per hour.
(1+ 0.0007 Tsh)= Superheat factor.
Tsh = Superheat temperature in degress F.

2.11 = Compressibility and conversion factor.
P_e = Absolute pressure of the steam entering the valve (psia).
P_o = Absolute pressure of the steam entering the coil (psia).
P = Pressure drop through valve (psid).

Tsh is the Fahrenheit superheat temperature of the steam reduced to the lower pressure from the higher pressure.

f. For superheated steam applications where the pressure drop across the valve at or greater than the valve's critical pressure, the C_v will be calculated using equation 2-9.

$$C_v = \frac{Q (1 + 0.0007 T_{sh})}{1.74 P_e} \quad (\text{eq. 2-9})$$

Where:
C_v = Valve flow coefficient (gpm per psid).
Q = Pounds of steam per hour.
(1+ 0.0007 Tsh)= Superheat factor.
Tsh = Superheat temperature in degrees F.
1.741 = Compressibility and conversion factor.
P_e = Absolute pressure of the steam entering the valve.

g. An example of the calculation required for the C_v of a valve designed to handle saturated steam when the pressure drop will be less than critical is as follows: An air coil requires 250 pounds of steam per hour entering the coil at 2 psig. The steam is generated by a local boiler with the boiler's operating pressure switches set at 5 psig "on" and 8 psig "off". Assuming 5 psig at peak load at the valve inlet and 2 psig at the valve outlet, the C_v is 11.34 as a result of using equation 2-6. In this example, critical pressure drop is not a limiting factor, because the coil pressure at critical pressure drop would be (14.7 + 5) x 0.45 = 8.87 psia, which is not possible unless the system is designed to operate at a high vacuum. A check of manufacturers' literature shows C_v of 10, 12, and 13 and a 1-inch valve. A valve C_v of 12 would be a good design choice for this application.

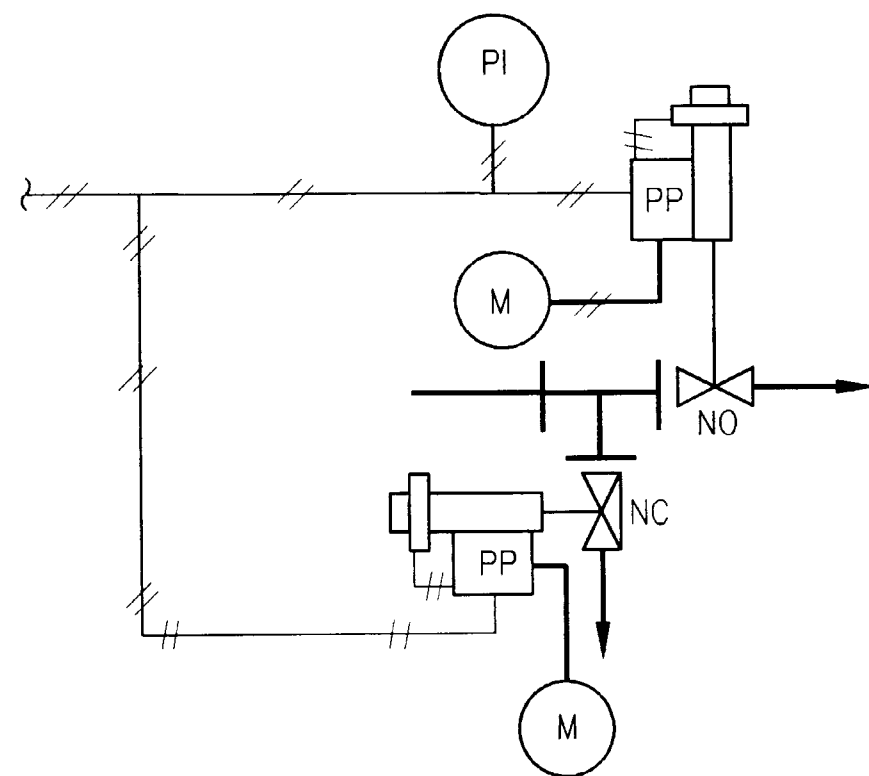
h. When the calculation for steam-valve selection results in a C_v of greater than 55, the designer will select two valves, with C_v chosen to split the flow unevenly between the valves; a good ratio is one-third of the flow for the smaller valve and two-thirds of the flow for the larger valve, which, however, is not always achievable from the normally available stock of valves. As an example of the calculation required, a steam converter requires 6,000 pounds per hour of steam at 1 psig entering the converter shell at peak load with the steam pressure reduced from 125 psig to 25 psig near the convertor. The critical pressure is 17.87 as a result of using equation 2-5, and the pressure drop across the valve is 25-1 = 24 psi, which is greater than the critical pressure. The constant-enthalpy process of reducing the steam pressure from 125 psig to 25 psig results in 48 degrees of superheat. The required C_v is

89.1 as a result of using equation 2-9. This C_v is 3 percent larger than it would have been if the steam were saturated at 25 psig and C_v were calculated from equation 2.7. In this example, the designer should show two valves in parallel and attempt to find available valves with C_v of approximately 60 and 30. A check of manufacturers' catalogs for this example results in the designer showing valves with C_v of 70 and 23 and a close-off pressure of 25 psig. The selection results from the following available control valve combinations, any of which will meet the design intent:

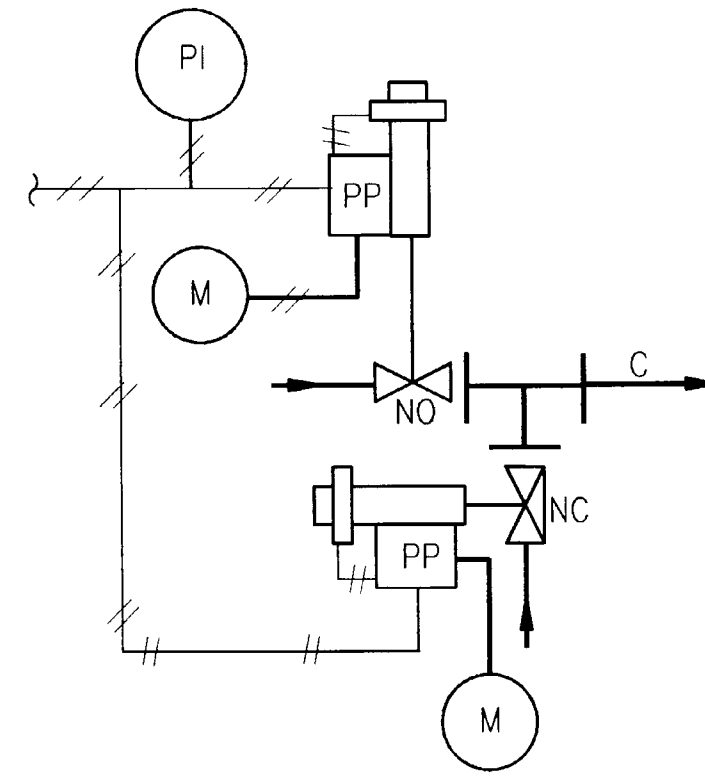
- (1) 1 valve 2½ inch size, $C_v = 74$ and 1 valve 1½ inch size, $C_v = 18$, or total $C_v = 92$
- (2) 1 valve 2½ inch size, $C_v = 70$, and 1 valve 1½ inch size, $C_v = 23$, or total $C_v = 93$
- (3) 1 valve 3-inch size, $C_v = 70.7$, and 1 valve 1½ inch, $C_v = 23.1$ or total $C_v = 93.8$

2-15. Surge-protection provisions for transmitter and control wiring

Because HVAC control-system transmitter signals and single-loop controller signals are interfaced with EMCS, the appropriate surge protection will be provided in the HVAC control system design as described in TM-5-815-2.



3-WAY BYPASS APPLICATION



3-WAY MIXING APPLICATION

Figure 2-1. Two butterfly valves on a common pipe tee.

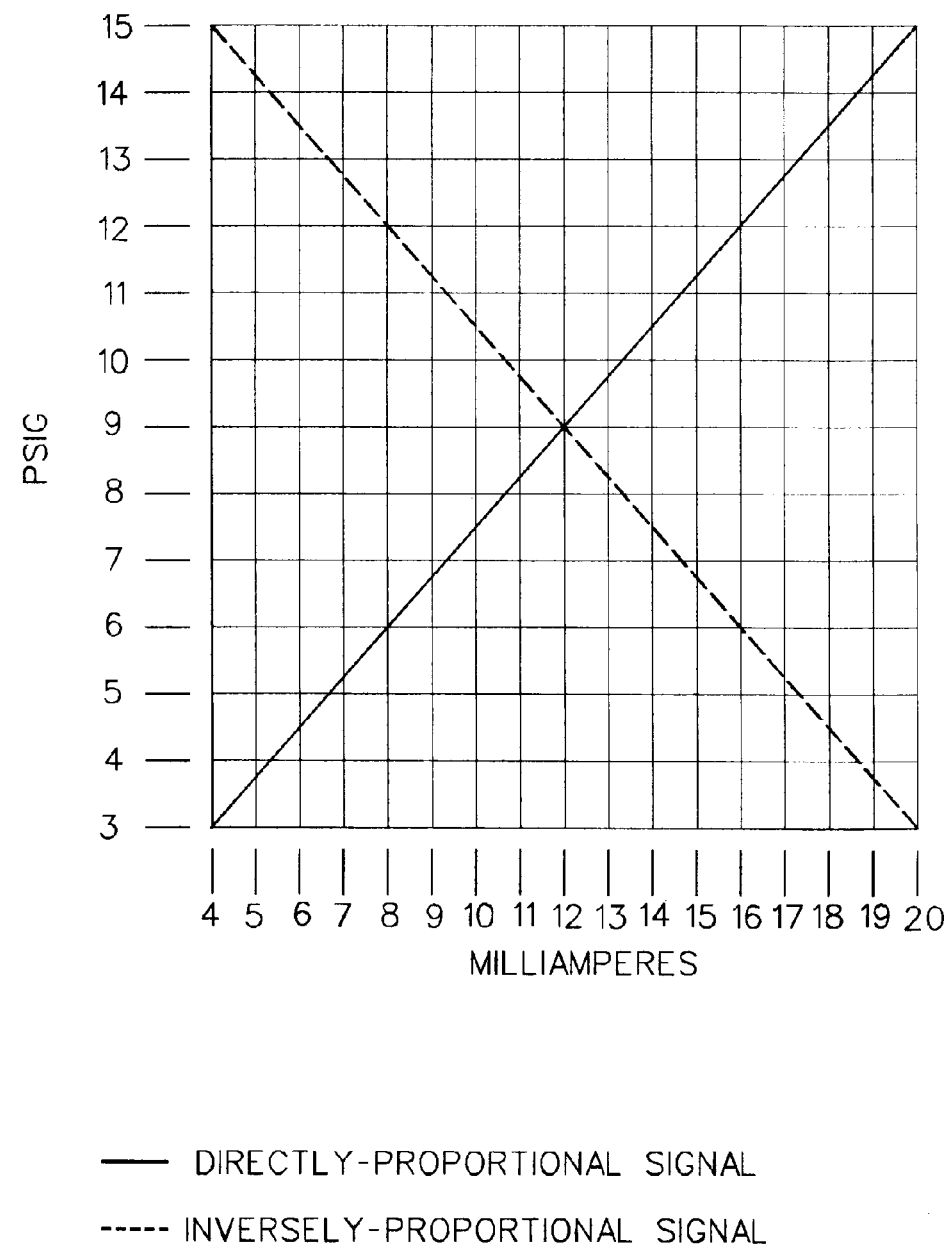


Figure 2-2. Conversion of an electronic signal to a pneumatic signal.

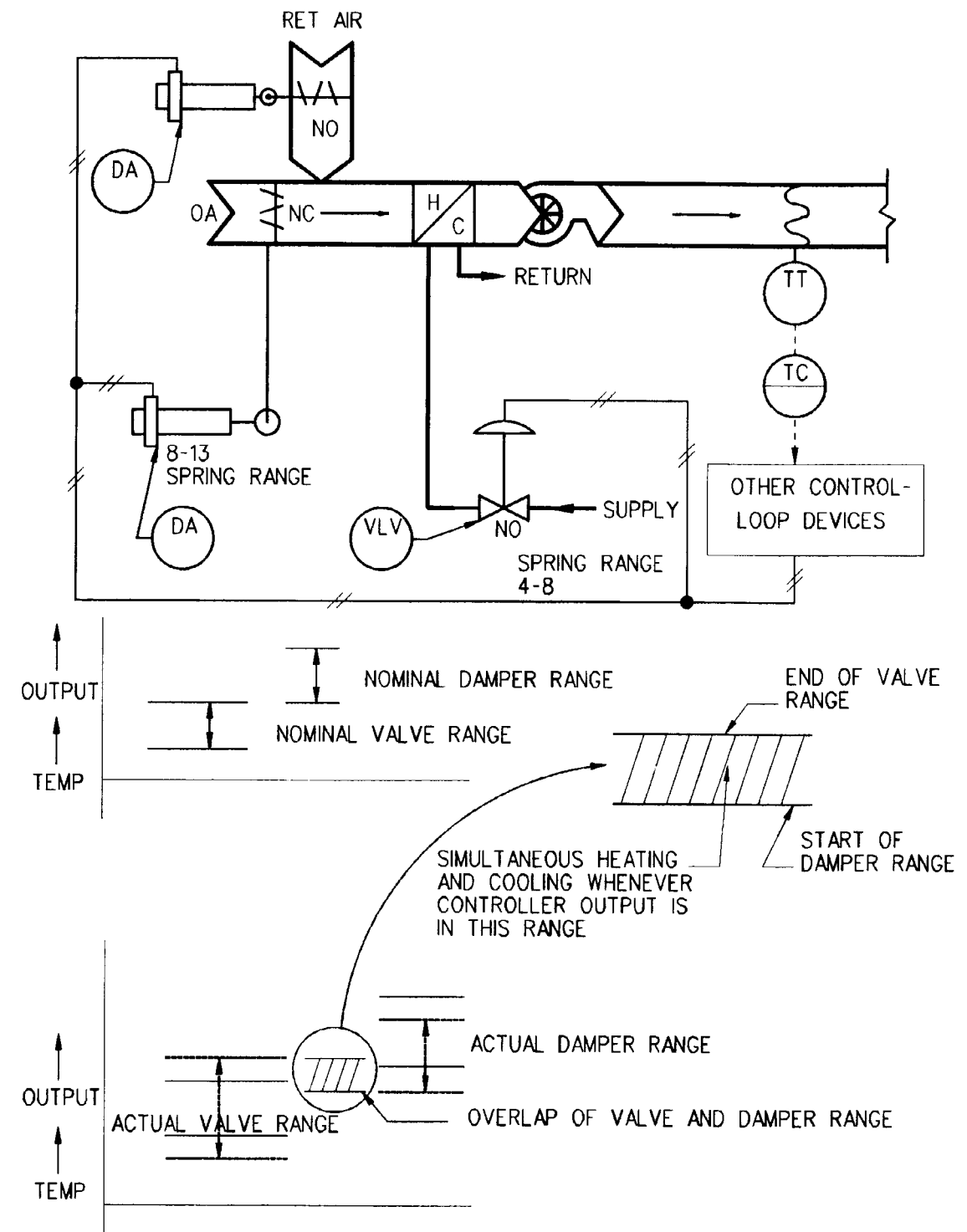


Figure 2-3. Simultaneous heating and cooling with pneumatic actuators without positive positioners.

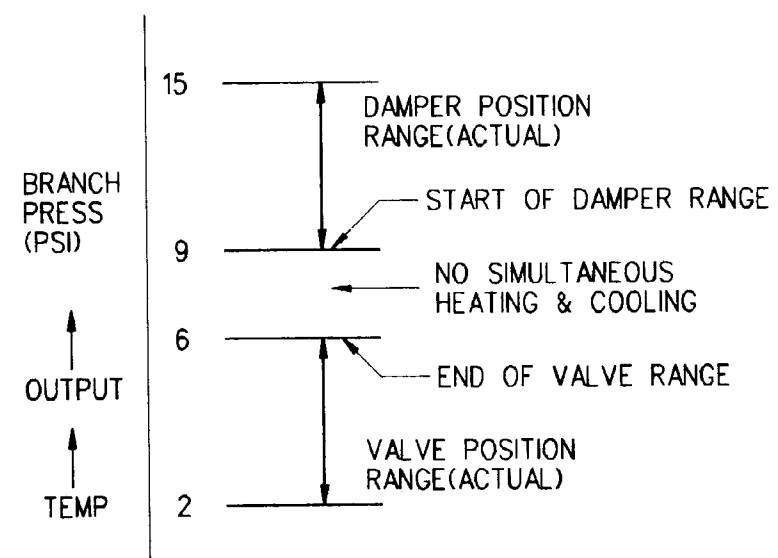
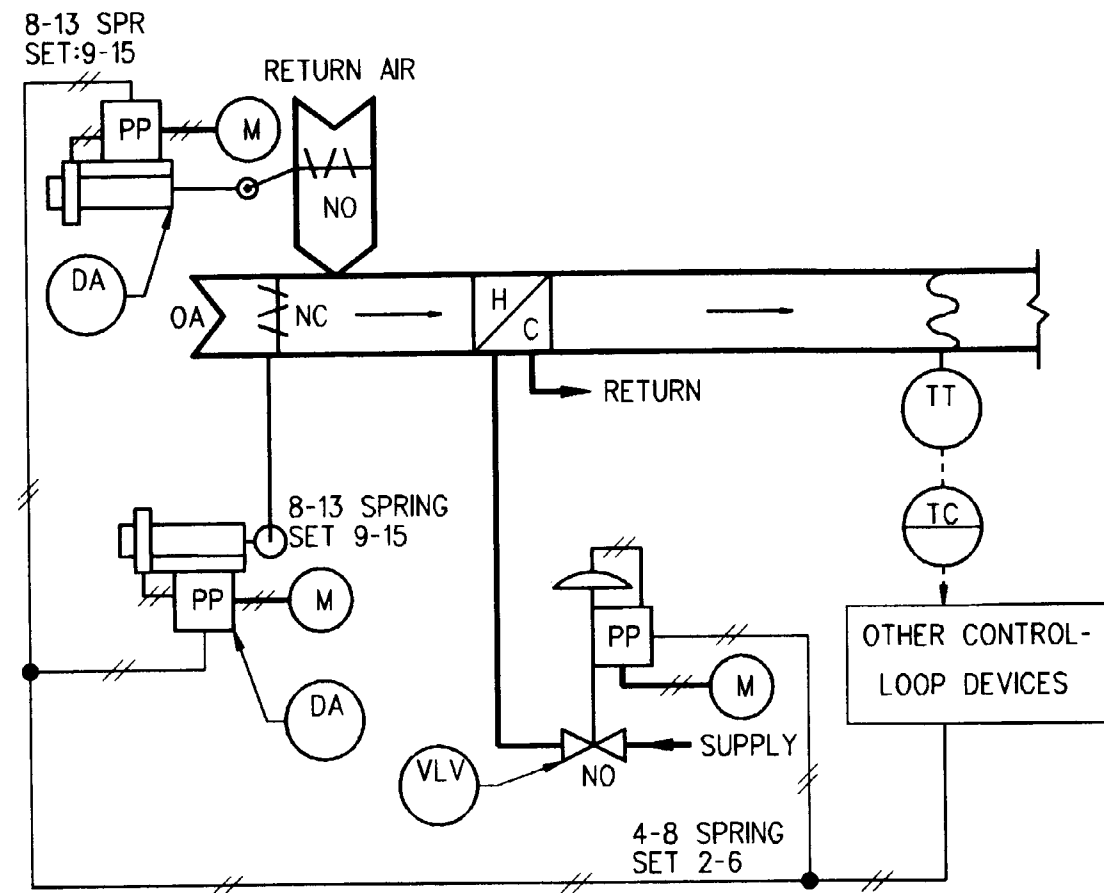


Figure 2-4. Control system with positive positioners to avoid simultaneous heating and cooling.

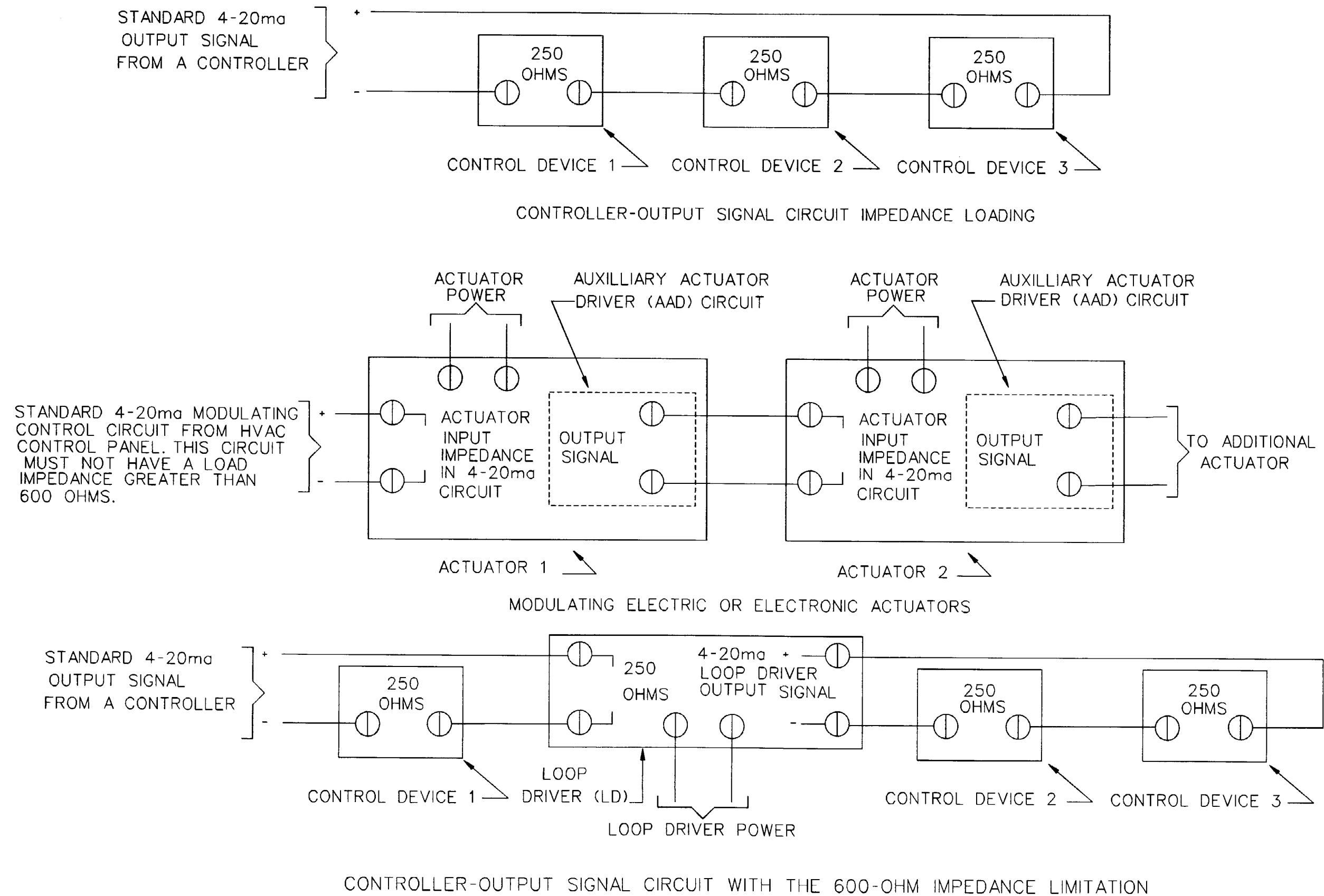
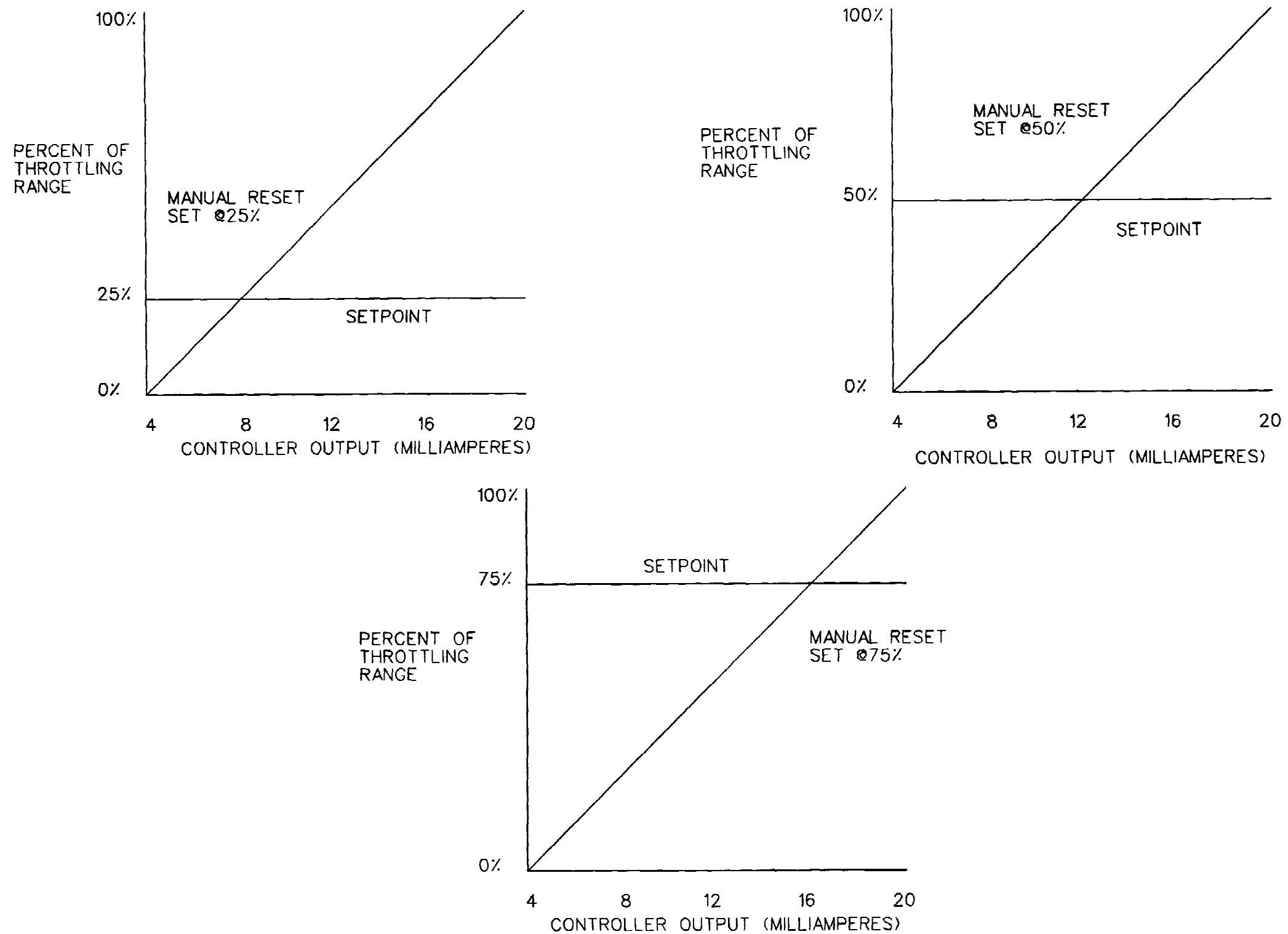


Figure 2-5. Modulating-control-circuits impedance limitation.



MANUAL RESET FEATURE

Figure 2-6. Manual reset feature.

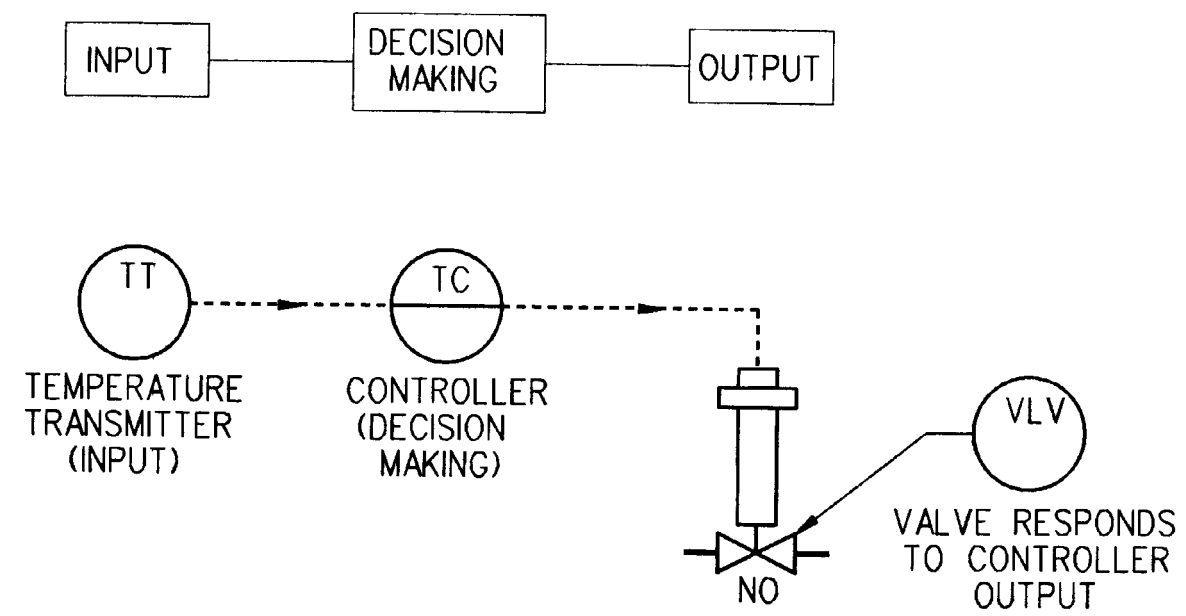


Figure 2-7. Control loop.

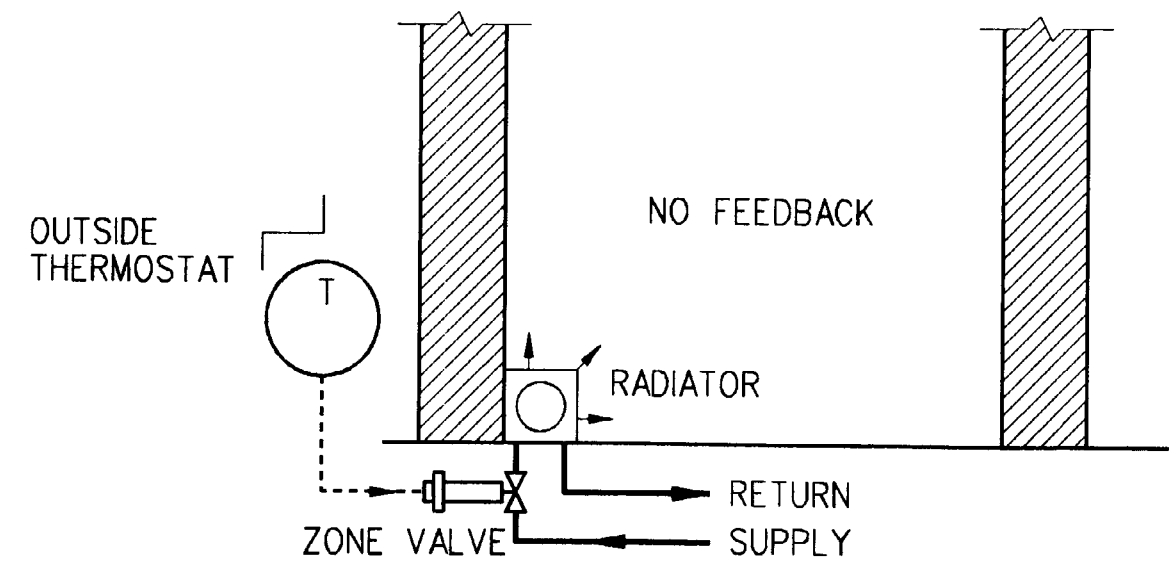


Figure 2-8. Open control loop.

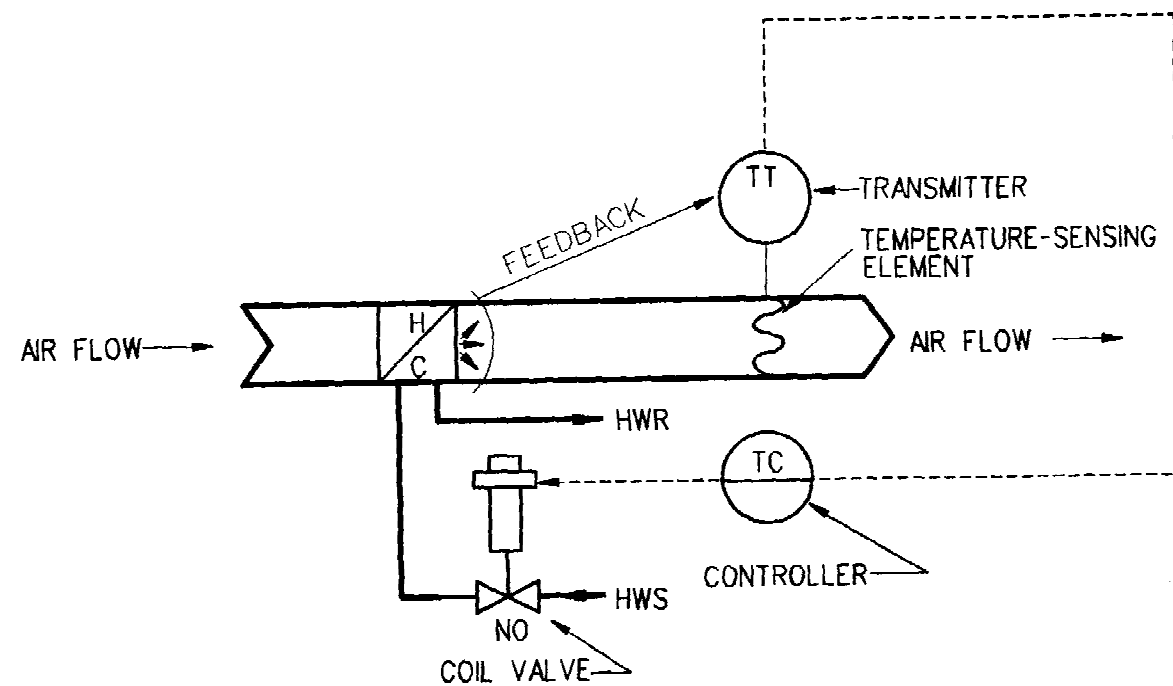


Figure 2-9. Closed control loop.

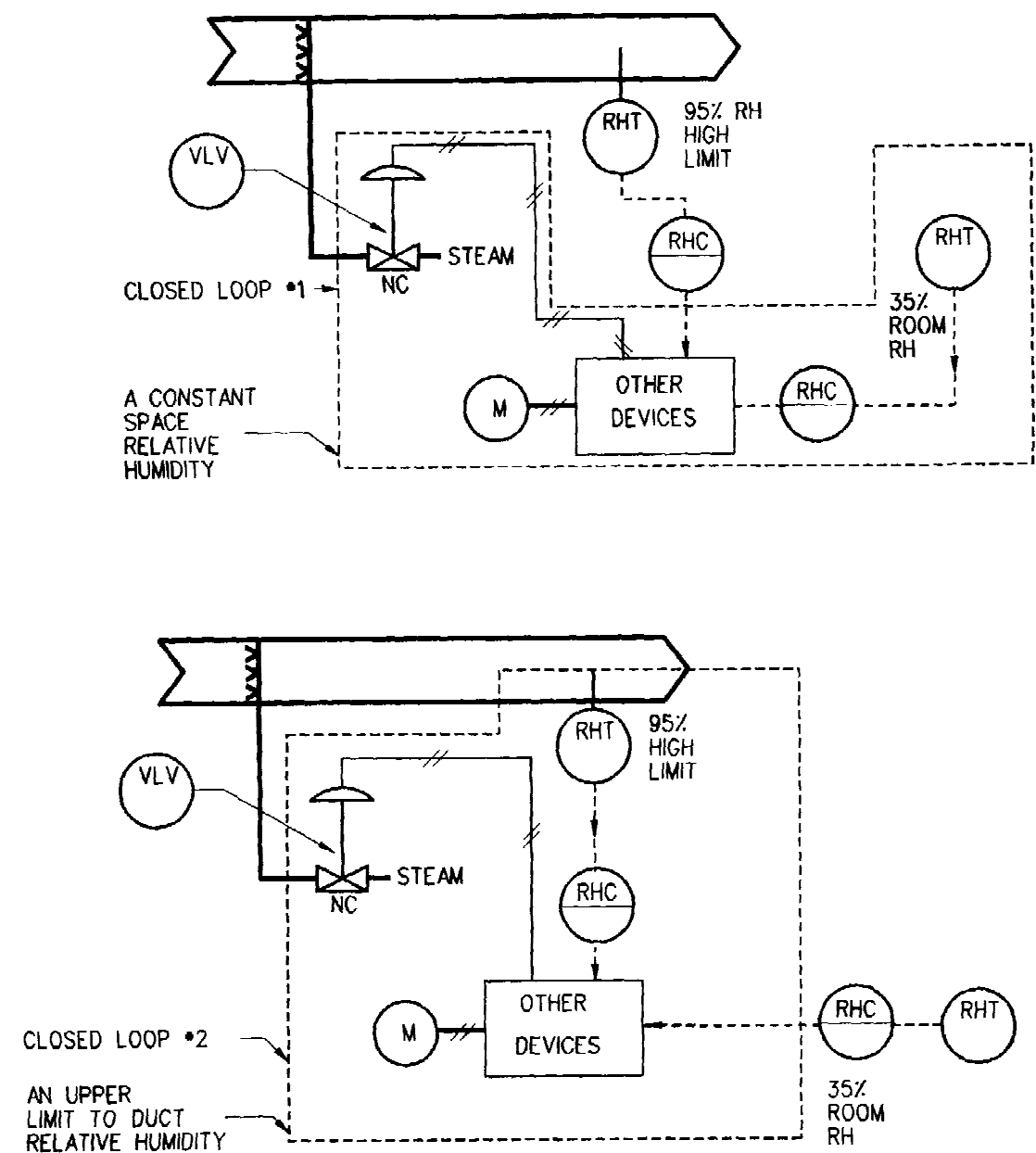


Figure 2-10. Two loops controlling one device (humidity control with high limit).

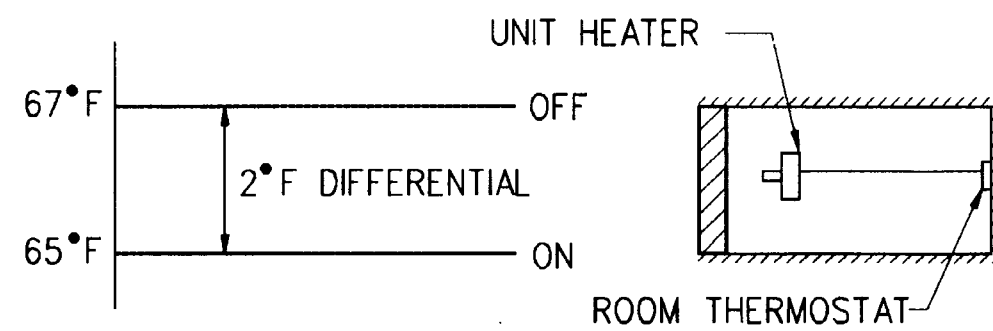


Figure 2-11. Two-position control.

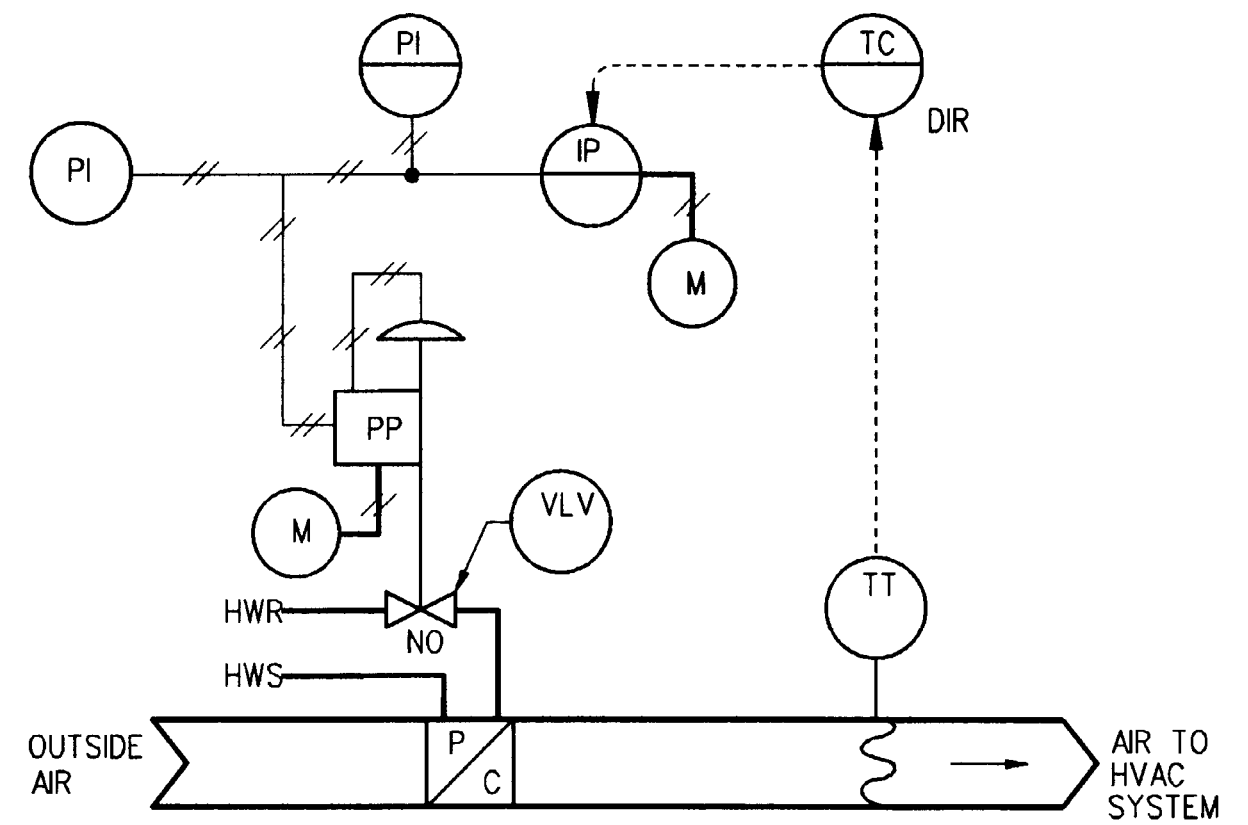


Figure 2-12. Simple control loop applied to outside-air heating.

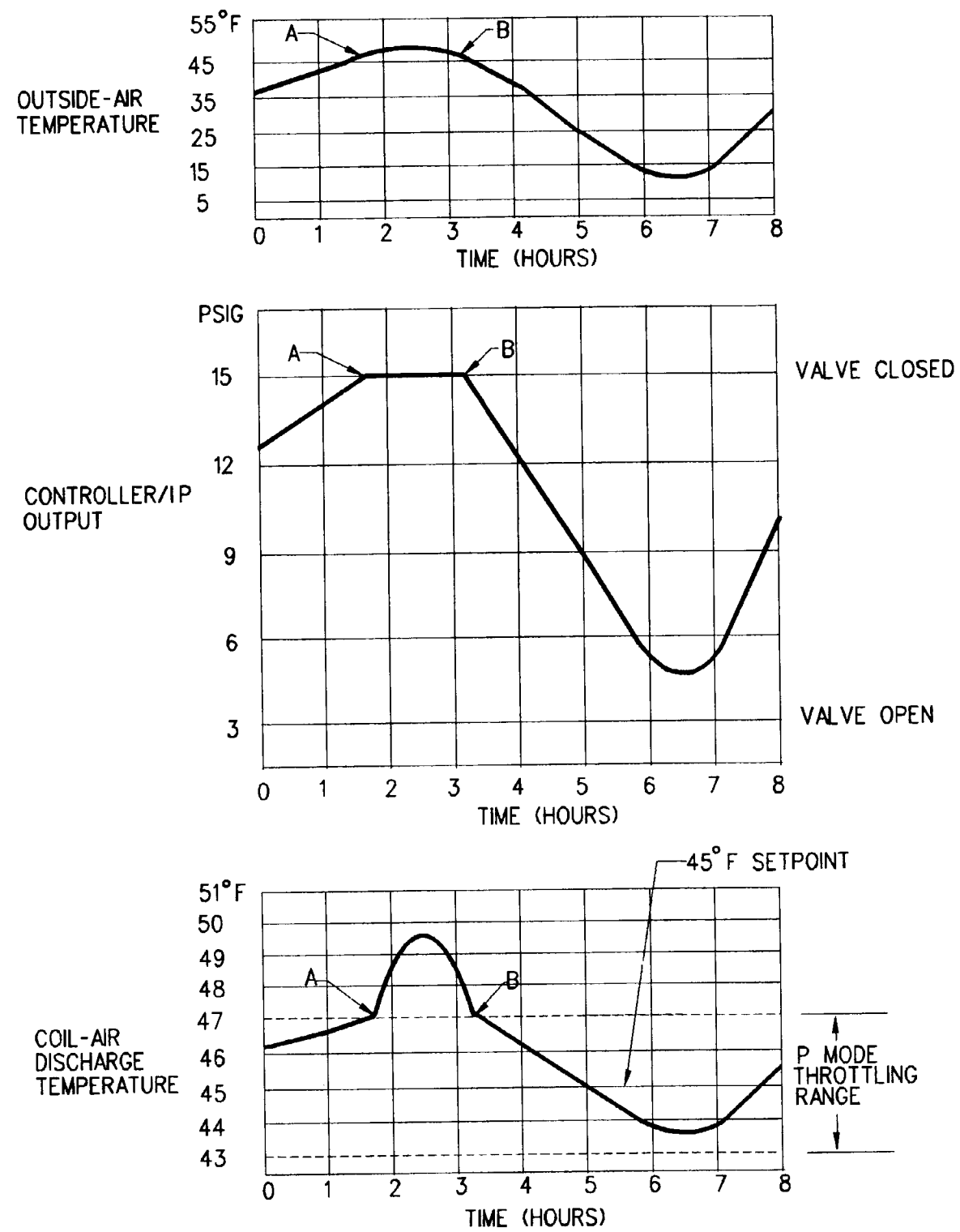


Figure 2-13. Proportional-control mode.

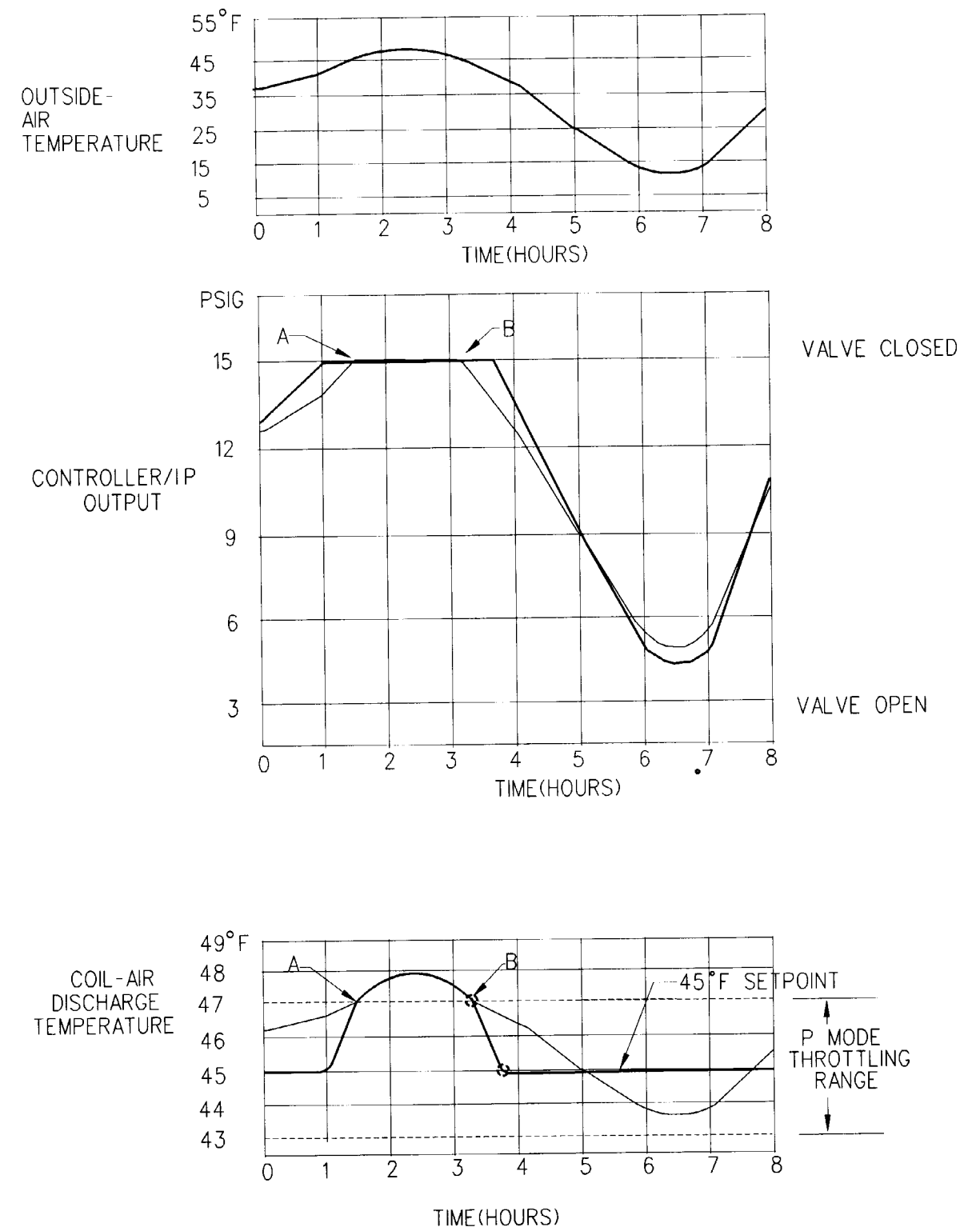


Figure 2-14. Proportional-plus-integral control mode.

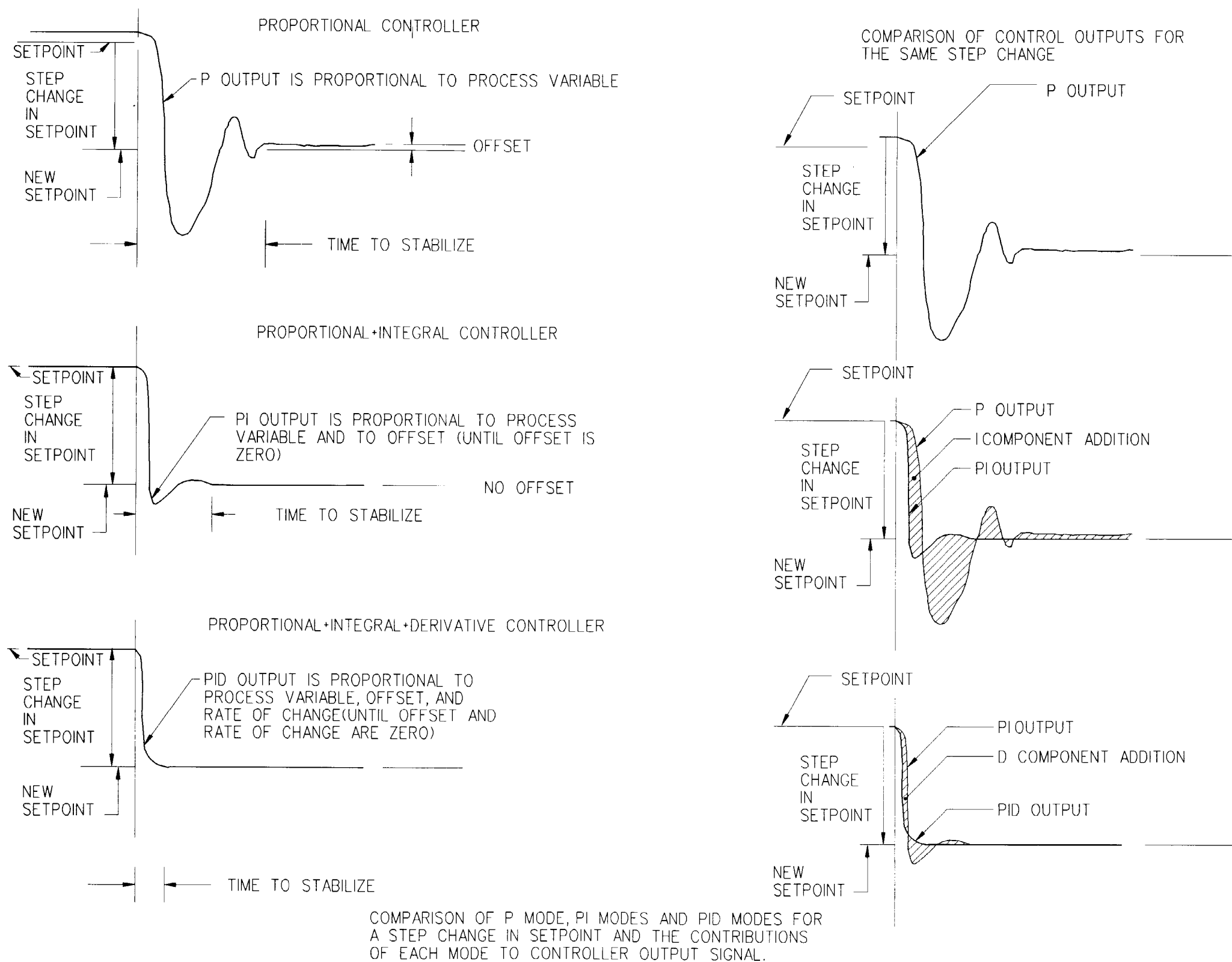


Figure 2-15. Comparison of P mode, PI modes and PID modes for a step change in setpoint, and the contributions of each mode to controller-output signal.

Chapter 3

Standard Control Loops

3-1. General

The standard control loops described in this chapter consist of control-system equipment and devices, arranged to perform specific control-system functions. In the ensuing discussions of the different types of control loops, all loop devices (including transmitters) are shown, and their associated indicators (such as thermometers) are included where required. The sensing elements are included with the transmitters and are not shown separately. Signals from the transmitters represent the changing conditions at the sensing elements. Also, the required panel-mounted and field-mounted pneumatic indicators are shown. Modulating-control signals from controllers are converted from 4-20 milliamperes to 3-15 psig by a current-to-pneumatic transducer (IP) connected to a positive positioner (PP) of a valve or damper actuator as applicable.

3-2. Cooling-coil-temperature control loop

a. The cooling-coil-temperature control loop is a constant-temperature control loop and is shown in figure 3-1. Temperature-sensing element and transmitter TT sends a temperature signal to controller TC, which modulates an IP. The pneumatic signal from the IP is connected to positive-positioner PP, which operates cooling-coil valve VLV. The conditions that must be operative for the control valve to be controlled are: the supply fan is on and the control system is in the occupied mode.

b. A relay contact between TC and IF is open when either constraint is operative.

3-3 Outside-air preheat-coil-temperature control loop

a. When the mixed-air temperature of the outside air and the return air is too low, a preheat coil will be used to heat the outside air. This modulating-control loop will be used only with hot-water or hot-glycol heating units. A variation of the preheat-coil control loop for use with steam preheat coils is shown in chapter 5. The purpose of raising the mixed-air temperature is to prevent freezing of chilled-water coils and hot-water coils downstream of the mixed-air plenum. The coil is sized to raise the temperature of the maximum design quantity of outside air just high enough to bring the mixed-air temperature within the range of 45 to 50 degrees F. The loop controls the temperature of the air leaving the preheat coil before the air mixes with return air. The setpoint of the controller of this loop is the HVAC system designer's calculation of the coil-discharge-air temperature required to maintain a minimum temperature in the mixed-air plenum when the outside-air is at the coldest temperature. This setpoint assures an adequate minimum temperature entering the cooling coil of an HVAC system. The outside-air preheat-coil-temperature control loop is shown in figure 3-2.

b. A temperature-sensing element and transmitter TT, in the discharge-air stream from the preheat coil, sends a temperature signal to preheat-coil temperature controller TC. Controller TC operates transducer IF to maintain the

setpoint of the controller by modulating a valve VLV. Since the TC setpoint is normally in the range of 40 to 55 degrees F, the valve is controlled during the heating season when the outside-air temperature is below the TC setpoint. When the outside-air temperature is at or above the TC setpoint, VLV is closed.

c. In this control loop, TC is direct-acting DIR, and VLV is normally open (NO) and fails open under the pressure of the valve actuator's return spring on loss of electric signal, pneumatic signal, or positive positioner air supply. The purpose of this is to avoid freezing of the preheat coil and other coils in the HVAC system should such an event occur in cold weather.

d. The preheat-coil control loop functions continuously, without regard to the operating condition of the HVAC system. This has the advantage of maintaining a minimum temperature in the ductwork when the HVAC system supply fan is off.

3-4. Heating-coil-temperature control loop

a. When they are not sequenced with cooling coils, heating coils of HVAC systems are controlled by either of the following methods:

(1) Controller setpoint scheduled from outside-air temperature.

(2) Controller setpoint fixed.

b. Control via the setpoint scheduled from the outside-air temperature occurs with the greater frequency. Figure 3-3 shows the heating-coil-temperature control loop scheduled from outside-air temperature for the purpose of conserving energy. This loop is shown as it is used to control heating coils for multizone HVAC systems or dual-duct HVAC systems. If a preheat coil is used in the design of the HVAC system, the temperature-sensing element in the outside air must be located upstream of the preheat coil. Controllers TC REV and TC DIR receive temperature-transmitter input signals with differing calibrated input ranges as shown. Temperature-sensing element and transmitter TT in the outside-air intake of the HVAC-system sends a signal to process-variable input PV of controller TC REV. Controller TC REV also reverses its output signal relative to the outside-air-temperature transmitter signal. The signal reversing is necessary because the setpoint of TC DIR must change in the opposite direction from that of change in outside-air temperature. Controller TC DIR operates heating-coil valve VLV. Temperature-sensing element and transmitter TT in the coil-discharge air sends a signal to process-variable input PV of TC DIR. Temperature-sensing element and transmitter TT in the outside-air intake signals TC REV, to raise the TC DIR setpoint when the outside-air temperature decreases and to gradually lower the TC DIR setpoint, in a linear schedule, as the outside-air temperature increases. Companion thermometers are shown where required. The limits of the control point adjustment (remote setpoint input) (CPA), to prevent the temperature schedule from exceeding 120 degrees F or decreasing below 90 degrees F, are set by limiting the maximum and minimum outputs of controller TC REV.

c. The temperature schedule (selected for illustration) desired for the heating-coil leaving-air temperatures is 120 degrees F at 0 degrees F outside-air temperature and 90 degrees F at 60 degrees F outside-air temperature, as shown in figure 3-3.

d. In order to achieve the schedule shown in figure 3-3, certain controller parameters must be calculated for controller TC REV. Controller TC REV output is the outside-air temperature schedule input to the remote-setpoint input (CPA) of heating-coil temperature controller TC DIR. These controllers have differing calibrated input ranges. The output of TC REV at 0 degrees F and 60 degrees F must match the input required to set TC DIR to 120 degrees F and 90 degrees F, respectively. The parameters for TC REV which match the output of TC REV to the required CPA reset range of TC DIR and the input range of its input transmitter are: the controller proportional band, the setpoint, and the minimum and maximum output settings. The output of TC REV must set TC DIR to a temperature setpoint of 120 degrees F when the outside-air temperature is 0 degrees F, and set TC DIR to a temperature setpoint of 90 degrees F when the outside-air temperature is 60 degrees F. These points define a line on a coordinate system of outside-air temperature as the abscissa and discharge-air temperature as the ordinate. All points on this line can be found by the use of equation 3-1.

$$y = mx + b \quad (\text{eq.3-1})$$

Where:

- y = ordinate (discharge-air temperature).
- m = slope of line between points on the line.
- x = abscissa (outside-air temperature).
- b = the y-axis intercept.

The slope of the line (m) connecting the abscissa points of 0 degrees F and 60 degrees F outside-air temperature and the ordinates of 120 degrees F and 90 degrees F discharge-air temperature is found to be minus 0.5 [(120-90)/(0-60)]. The value of the y-axis intercept (b) is found by setting the value of x at 0 degrees F, and is found by equation 3-1 to be 120 degrees F. The required throttling range of TC REV is found by using equation 3-1 and setting the value of y at the extremes of the calibrated input range of TC DIR. On the lower end of range of TC DIR, the value of y is calculated to be 160 degrees F, and the value of y at the upper end of the range is calculated to be minus 40 degrees F. From these calculated values, the temperatures span of the throttling range of TC REV is calculated as 200 degrees F [160 - (-40) = 200]. Because the setpoint must be at the midpoint of a 200 degree F throttling range extending from minus 40 degrees F to 160 degrees F, the setpoint of TC REV is calculated to be 60 degrees F [-40 + 200/2 = 60 or 160 - 200/2 = 60]. Use of equation 2-1 to calculate the proportional band setting results in a value of 125 percent proportional band (PB - 200/160 x 100 percent) when 200 degrees F is used as the portion of the span required for the throttling range and 160 degrees F is the transmitter span. Because the span of the throttling range exceeds the span of the transmitter, the proportional

band is greater than 100 percent. This means that the output of TC REV is limited by the limits of its input transmitter values. Discharge-air-temperature setpoints beyond those shown for minus 30 degrees F and 130 degrees F. outside-air temperature cannot be scheduled in this example. The output of controller TC REV cannot achieve a full-scale change because of the combination of the proportional-band setting and the calibrated input range of TC REV, which must match that of the outside-air temperature transmitter. The schedule of discharge-air temperatures can be further limited by setting the minimum and maximum output limits of TC REV. The controller's maximum output setting is calculated to be 80 percent [(160-0) degrees F/160 - (-40) degrees f x 100 percent = 80 percent]. The controller's minimum output setting is calculated to be 50 percent [(160-60) degrees F/[160-(-40)] degrees F x 100 percent = 50 percent]. Using the calculated values for proportional band, setpoint minimum output and maximum output will result in a controller input/output schedule as shown in figure 34, which shows the output of TT, OA for every 10 degree F change represented by a change of 1 ma [(20-4) ma/160 degrees F x 10 degrees F = 1 ma], and the input of TC DIR for every 5 degrees F represented by a change of 0.8 ma [(20-4) ma/100 degrees F x 5 degrees F = 0.8 ma].

e. The heating-coil temperature-control loop, with its fixed-controller setpoints, is similar to the preheat-coil-temperature control loop in that it also controls the coil valve at all times. Figure 3-5 shows the heating coil controlled in a fixed-temperature application. Temperature-sensing element and transmitter TT sends a signal to heating-coil temperature controller TC. The operations of the control devices affected by the output signal of TC are identical, as previously described in paragraph 3-3b.

f. The heating-coil-temperature control loop functions continuously, without regard to the operating condition of the HVAC system. This has the advantage of maintaining a minimum temperature in the ductwork when the HVAC-system supply fan is off.

3-5. Mixed-air-temperature and economizer control loops

a. The mixed-air-temperature and economizer control loops are shown in figure 3-6. The actuators on the dampers operate like the actuator on a control valve. The outside-air damper and relief-air damper are normally closed and operate in parallel with each other. the return-air damper is normally open and works opposite to the outside-air and relief-air dampers. The mixed-air-temperature control loop is linked to the economizer-control logic.

b. Outside air will not be used when the control system is in the unoccupied mode or in the ventilation-delay mode. A normally open (NO) relay contact in the circuit to IP keeps the outside-air damper closed under these conditions, and also when the supply fan is off. An open relay contact in the circuit between TC and high-signal selector TY keeps the dampers open to the manual setting of minimum-position switch MPS, when the system is in

the minimum-outside-air mode, and the outside-air damper is allowed to open by the absence of other constraints. When both of these relay contacts are closed, the control system is then operating in both the occupied and economizer modes. Controller TC maintains the mixed-air temperature by controlling the IP to modulate the dampers beyond minimum position. The signal from MPS or the signal from TC operates through high-signal selector TY to operate the IP, which sends a pneumatic signal to positive-positioner PP to control the damper actuators. The output of IP to the damper-actuator positioners can be read on PIs at the panel and at the damper location. Mixed-air-temperature sensing element and transmitter TT, sends a signal to TC, which changes its output to operate the dampers between minimum outside-air position and full outside air.

c. The temperature-sensing elements and transmitters TT in both the outside-air intake and the return-air duct send temperature signals to economizer controller EC.

d. The economizer controller EC requires a setpoint for each of two contacts that determine whether the coil of the relay that puts the system in the occupied mode or unoccupied is energized or deenergized. The setpoints and switching differentials for each of the contacts are adjustable in EC. One of the contacts, configured as a PV contact, responds to the temperature-sensing element and transmitter TT in the return-air duct and prevents the economizer mode from operating when the HVAC system is heating the space that it serves. The return-air-temperature setpoint of the contact will be selected at a temperature that is below the expected cooling-season return-air temperature but higher than the expected heating-season space temperature. The other contact, configured as a deviation (DEV) contact, responds to the difference in the signals of outside-air temperature and return-air temperature. The setpoint of the DEV contact requires a calculation by the designer. The designer will indicate the return-air temperatures at which the PV contacts open and close and the temperature differences between the outside-air temperature and the return-air temperature at which the DEV contacts open and close.

e. Because of the difficulty of maintaining enthalpy-based economizer switchover hardware, the economizer-controller operation is based on dry-bulb temperature measurements rather than enthalpy measurements. The comparison of outside-air and return-air temperatures for determining the economizer switchover point is a method of control that uses local weather data for selecting an optimum dry-bulb temperature difference. An explanation of this method begins with figure 3-7.

f. The skeleton psychrometric chart shows a return-air design condition of 75 degrees F dry-bulb temperature and 50 percent relative humidity. A constant-enthalpy line drawn through this condition divides the chart into 4 regions of outside-air temperatures and outside-air relative humidities, which are:

- (1) Region A, in which temperature and enthalpy conditions are less than return-air design conditions.
- (2) Region B, in which temperature conditions are

lower but enthalpy conditions are higher than return-air design conditions.

(3) Region C, in which both temperature and enthalpy conditions are higher than the return-air design conditions.

(4) Region D, in which temperature conditions are higher but enthalpy conditions are lower than return-air design conditions.

g. Cooling energy can be saved by using outside-air for cooling when outside-air conditions are in region A. Less energy will be used in cooling outside air than in cooling return air when outside-air conditions are in region D. When outside-air conditions are in region B, the outside-air dry-bulb temperature is less than the return-air dry-bulb temperature; however, excess cooling energy would be used if more than the required minimum of outside air is used, because the enthalpy of the outside air is higher than the design return-air condition. When outside-air conditions are in region C, there is no energy saving available from the use of outside air. The designer will consult the local weather data for the nearest location of the project as published in TM 5-785. Using a Lpsycho-metric chart, the designer will use the following procedure to determine the setting of the DEV contact:

(1) Plot a constant-enthalpy line through the Lreturn-air design temperature and relative-humidity condition.

(2) Plot an average-weather line by using midpoint of the 5 degree Fahrenheit bin and the mean coincident wet-bulb temperature for that temperature bin from TM 5-785.

(3) Read the difference in dry-bulb temperature between the design return-air temperature and the outside-air temperature where the average-weather line crosses the constant-enthalpy line.

(4) Use this difference in dry-bulb temperatures as the setting for the DEV contact.

h. An example of the application of this procedure is shown in figure 3-8.

i. Figure 3-8 illustrates the method for selection of a setpoint for the DEV contact for economizer-mode switch-over in a relatively humid southeastern United States city, based on published weather data. The method presumes that the location is such that an economizer mode is acceptable in the HVAC design because it would not place an energy burden on the system due to a requirement for humidification of more than the minimum quantity of outside air. The temperature-differential setpoint of the DEV contact is shown as 8 degrees F. However, the temperature differential determined by this method will vary with: the design return-air conditions; and the Laverage-weather line for the locality. Less-humid climates will tend to shift the average-weather line downward toward the design return-air condition, which would result in a smaller differential. The effect on energy conservation of using this method is shown in figure 3-9.

j. Figure 3-9 shows that the dry-bulb-temperature line at the intersection of the average-weather line and the constant-enthalpy line bisects region B. The area shown as region B-I represents outside-air conditions when the economizer mode will not save cooling energy even though outside air beyond the minimum quantity will be used if

the control system modulates the dampers open. The net effect on energy use depends on how many operating hours per year of the HVAC system are coincident with the occurrence of the outside-air conditions of region B-1.

3.6. Supply-duct static-pressure control loop

The supply-duct static-pressure control loop is shown in figure 3-10. A differential-pressure sensing element and transmitter (DPT) sends a signal to static pressure controller PC, which operates IP to control DA, which in turn operates fan inlet vane IV provided that the fan is on. DPT must have a relatively low range, such as 0.0 to 2.0 inches of water column. The supply fan may have been selected for a much larger static pressure, but the static pressure at the location of the DPT's sensor is typically 1.0 to 1.5 inches of water column. The sensing location of Dill' is approximately two-thirds of the distance from the supply fan along the duct calculated to have the greatest pressure drop. This sensing location insures that the static pressure will be controlled at the value required to enable all VAV boxes to function. The "Fan-On" relay contact disconnects PC from IP, causing DA to hold IV in the closed position (unloaded) on fan shutdown; the purpose in unloading the fan is to allow it to start unloaded. DPI is a low-differential-pressure gauge used as an indicator for Dill'. Details of the action of the rest of the control system devices connected to the IP's output are similar to comparable parts of other loops previously described.

3-7. Return-fan-volume control loop

The return-fan-volume control loop is shown in figure 3-11. Flow-sensing elements and linearized transmitters FTs in the supply air and the return air get signals from duct-mounted air-flow measurement stations and sensing arrays, AF MA. Both FTs send signals to controller FC. These signals are the information necessary to maintain a fixed flow difference (in cfm) between the supply-air and return-air ducts. The controller measures and controls the return-air flow through the PV input based on the supply-air flow measured at the CPA input. More than likely, the ranges of the air-flow velocities in each duct will be different because of differences in design velocity and in the cross-sectional areas of the ducts. The FTs in the supply-air duct and return-air duct may or may not have the same span and range. This means that a given flow rate in the supply duct may have a different signal level than the exact same flow rate in the return duct. In order for FC to control the return-air flow at a specific rate (cfm), the CPA signal from the supply fan FT must have the same value that will appear at PV when the set-point is achieved. To achieve this, the CPA signal from the supply duct must be converted to FC's ratio-and-bias feature to perform two functions. A ratio factor must be applied to the signal from the supply-air flow transmitter/air-flow measurement station (FT/AFMA) combination so that it will match the signal range of the return-air FT/AFMA combination. Also, the ratio is used to account for differences in the cross-sectional area of the ducts at the location of the measuring

stations. The signal must then be biased to maintain the design fixed airflow difference. For example, if the fixed difference is required to be 3,000 cfm for minimum outside-air requirements when the supply-air flow is 20,000 cfm, CPA tells FC to control PV at 17,000 cfm; when the supply-air flow is 12,500 cfm, CPA tells FC to control PV at 9,500 cfm. The 3000-cfm difference is the bias to be set in the controller in cfm units. The CPA signals at two such supply-air flow points must match the PV signals at two corresponding return-air flow points. When this is achieved at two points, the required results will be achieved for any supply-fan flow and the appropriate return-fan flows within the turndown capabilities of the return fan. The ratio can be calculated according to equation 3-2. Equation 3-2 assumes that the low end of the transmitter span is 0 fpm at 4 milliamperes for each transmitter.

$$R = (As/Ar)/(Vs/Vr) \quad (\text{eq. 3-2})$$

Where:

R = Ratio (dimensionless)

As = Area of supply-air duct at the measuring station (sq ft).

Ar = Area of return-air duct at the measuring station (sq ft).

Vs = Span of the flow transmitter in the supply duct (fpm).

Vr = Span of the flow transmitter in the return duct (fpm).

The bias is set in the controller in cfm units.

3-8. Humidifier control loop

The humidifier-control loop is shown in figure 3-12. Humidifier control-valve VLV is normally closed. It is inhibited from opening by the contact of a relay that is open unless the fan is on, the system is in the occupied mode, and the ventilation-delay period has expired. When these conditions of operation are met, space relative-humidity sensing element and transmitter RHT signals relative-humidity controller RHC to operate IP to control humidifier valve VLV. A high-limit relative-humidity controller RHC receives a signal from a duct relative-humidity sensing element and transmitter RHT downstream of the humidifier. Both controllers are reverse-acting. Low-signal selector RHV allows the space relative-humidity controller to operate the valve if the high-limit relative-humidity setpoint is not exceeded. The high-limit relative-humidity controller must be a proportional only controller.

3-9. The typical schematic

a. The integration of standard control loops into a standard system starts with a schematic. A typical schematic is shown in figure 3-13.

b. Figure 3-13 shows the control loops arranged around an airflow diagram. When showing the schematic, the designer will:

- (1) Label all HVAC equipment.
- (2) Label each control device with a unique identifier.

(3) Label the action (NC or NO) of all valves, dampers, and other appropriate devices.

(4) Label the action of all controllers as direct-acting DIR or reverse-acting REV.

(5) Label the input of all controllers (PV or CPA).

(6) For each device that operates contacts, show a line number on which each contact will appear on a ladder diagram.

(7) For each relay contact, show the line number of a ladder diagram on which the relay operating coil will appear.

(8) Show the location of all instruments not located in the flow stream or in the HVAC-control panel.

(9) Show a graphic representation of sequencing operations with open and closed positions versus controller output and space temperature.

3-10. The typical ladder diagram

a. When all the information necessary for a description of the system is now shown on the schematic, a ladder diagram will be required. A typical ladder diagram is shown in figure 3-14.

b. In the ladder diagram, the designer will:

(1) Show a section of the diagram for the HVAC control-panel logic.

(2) Show a section of the diagram for each starter-control circuit and interlock circuit for HVAC equipment.

(3) Label control devices and relays with their unique identifiers.

(4) Label magnetic-starter coils.

(5) If multiple-control devices of the same type (such as low-temperature-protection thermostats or smoke detectors) are required, assign a unique identifier for each and show its contact.

(6) Show separate relays to control AC and DC circuits.

(7) Number the ladder-diagram lines according to their control-power source.

(8) Show a switch, located in the HVAC control panel, to override the clock (or EMCS) and to be used to place the control system in continuous occupied mode (auto/auto override).

(9) Show a switch, located in the HVAC control panel, that can be used to shut down HVAC equipment and interlocked equipment (off/enable).

c. The HVAC-control-panel section of the ladder diagram will be in accordance with the following format:

(1) Line numbers will start with 0 for the clock circuit and continue as required.

(2) Control-system switches and contacts will be shown on the left of the diagram.

(3) Relay coils will be shown in the center of the diagram, centered below the clock circuit.

(4) Pilot lights will be shown on the right of the diagram.

(5) Contacts available to EMCS will be shown outside the ladder and to the right of the diagram.

d. Each section of the HVAC equipment starter-control circuits and interlock circuits will be in accordance with the

following format:

(1) The line numbers of the first section will begin with 100, the second section with 200, and subsequent sections with appropriate higher numbers in increments of one hundred.

(2) Magnetic-starter circuits will show one phase powering a control-circuit transformer, switches, fuse, and overload relays.

(3) The panel ladder diagram will have a jumper shown for connection to EMCS of an economizer enable and disable function. The panel ladder diagram will show terminal points for remote system shutdown and remote safety override control of HVAC system fans.

(4) Starter ladder diagrams will have an off-enable switch to allow HVAC system motors to be stopped from the HVAC control panel.

3-11. The typical equipment schedule

a. An equipment schedule is required to show the control-system parameters not shown on the schematic and the ladder diagram. Not all HVAC control devices shown on the schematic and the ladder diagram are included in the equipment schedule because it is not necessary to show parameters for them. Control devices that are excluded from the schematic are relays, IPs, loop repeaters, and signal selectors. A typical equipment schedule is shown in figure 3-15.

b. In the equipment schedule, the designer will:

(1) Arrange all control devices by loop function.

(2) Show the unique identifier as the device number.

(3) Name the device function.

(4) Show setpoints, ranges, time schedules, and other parameters.

(5) Show the selected Cv and required close-off pressure for each valve.

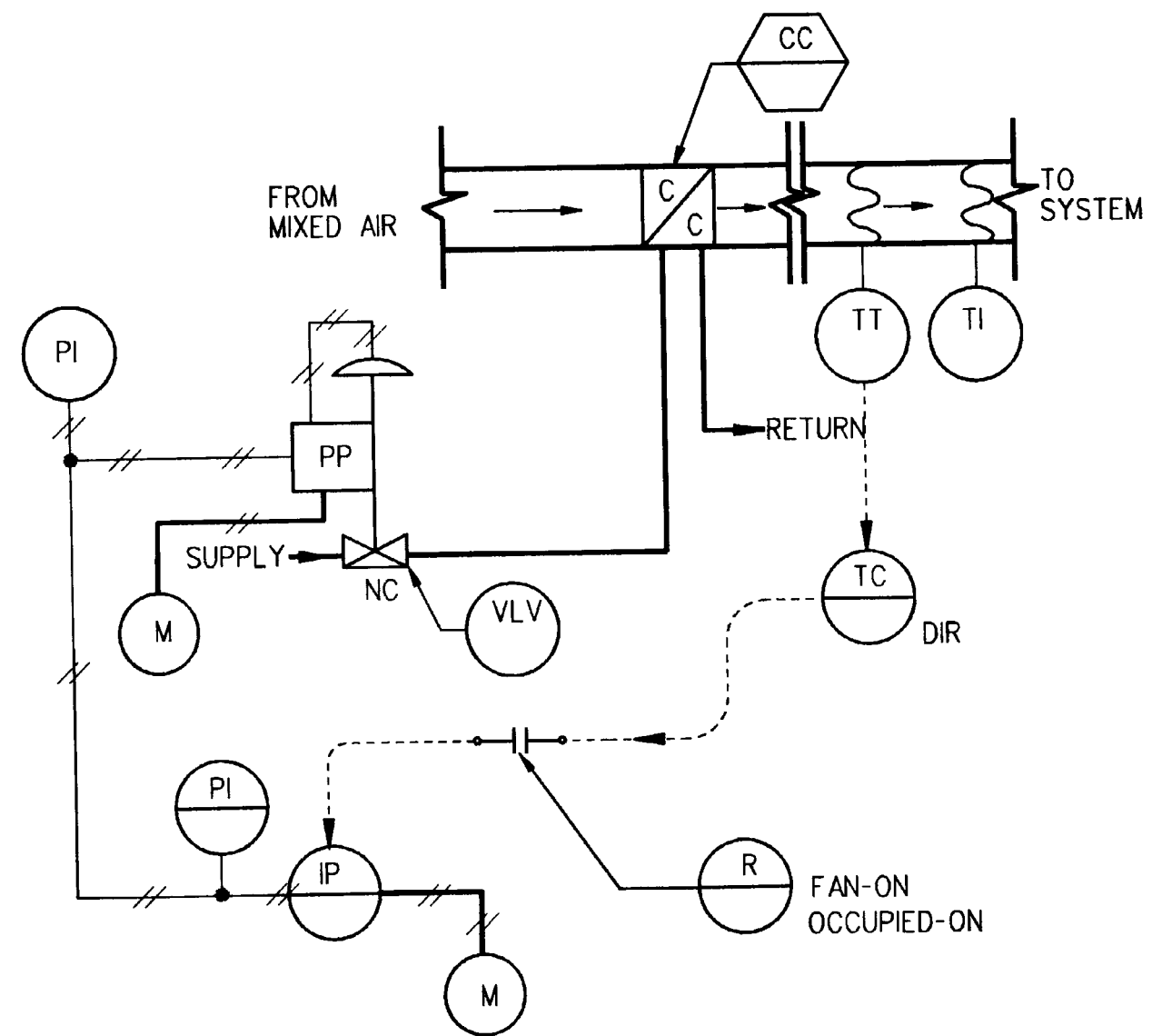


Figure 3-1. Cooling-coil temperature control loop.

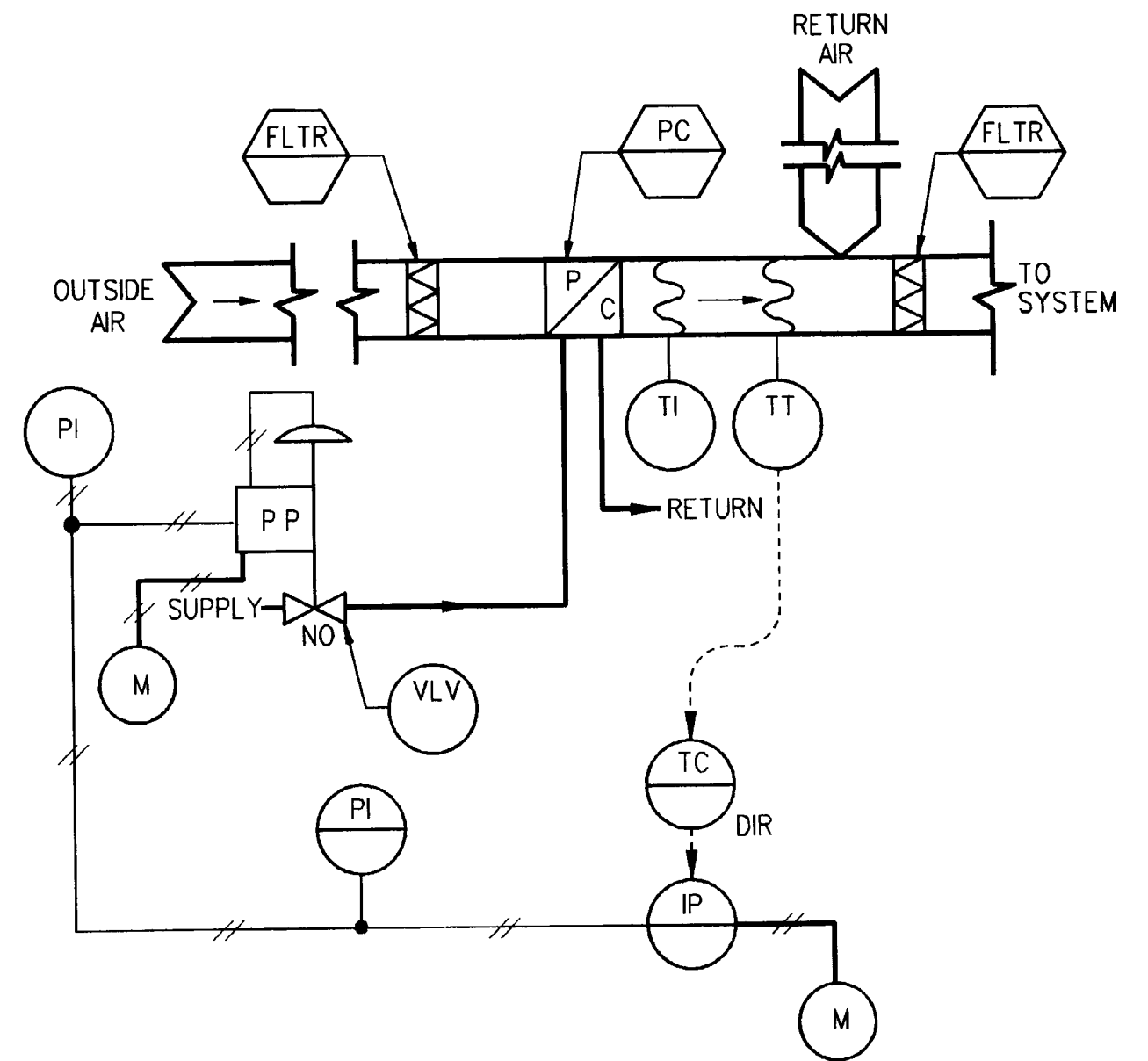


Figure 3-2. Outside-air preheat-coil-temperature control loop.

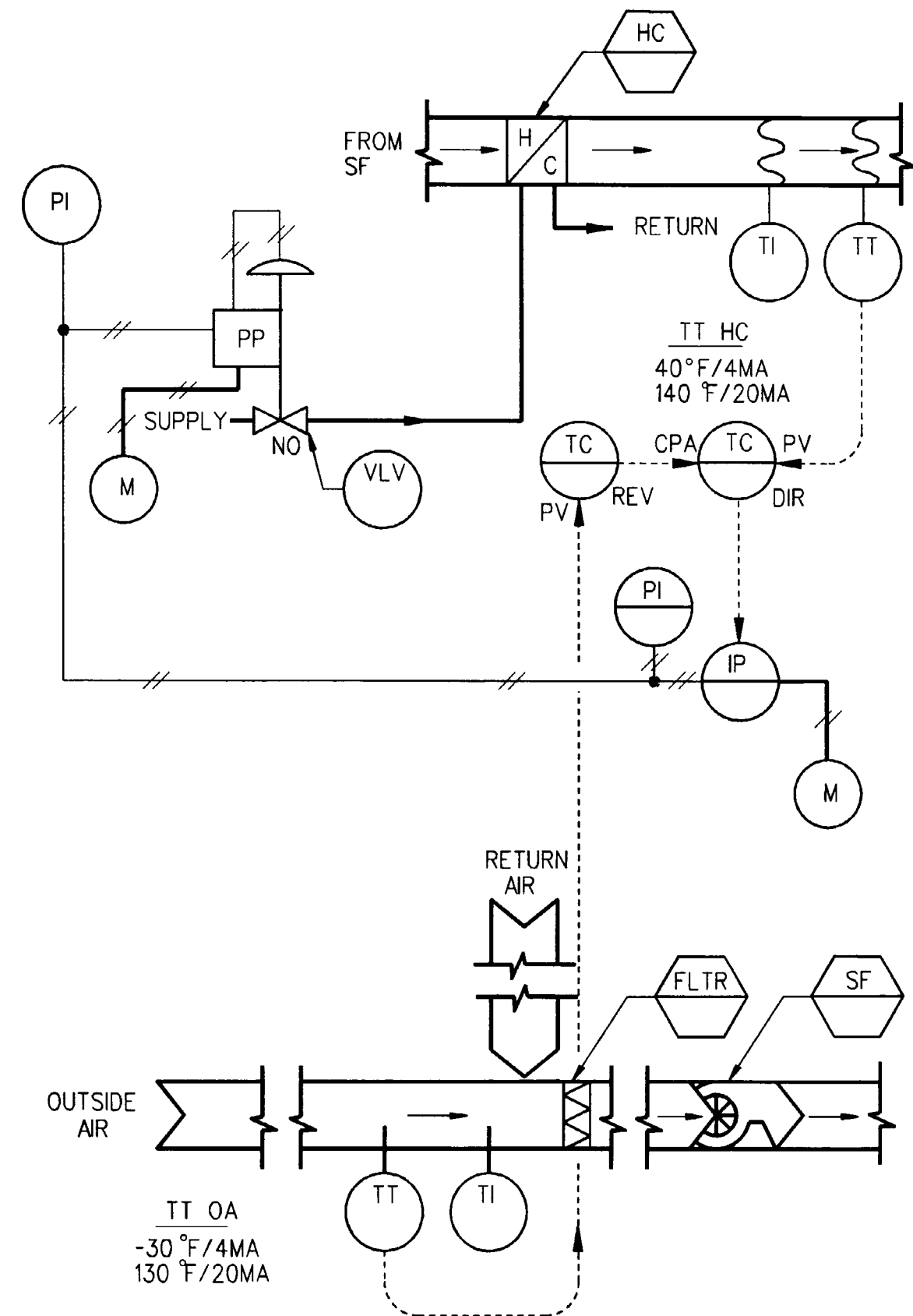
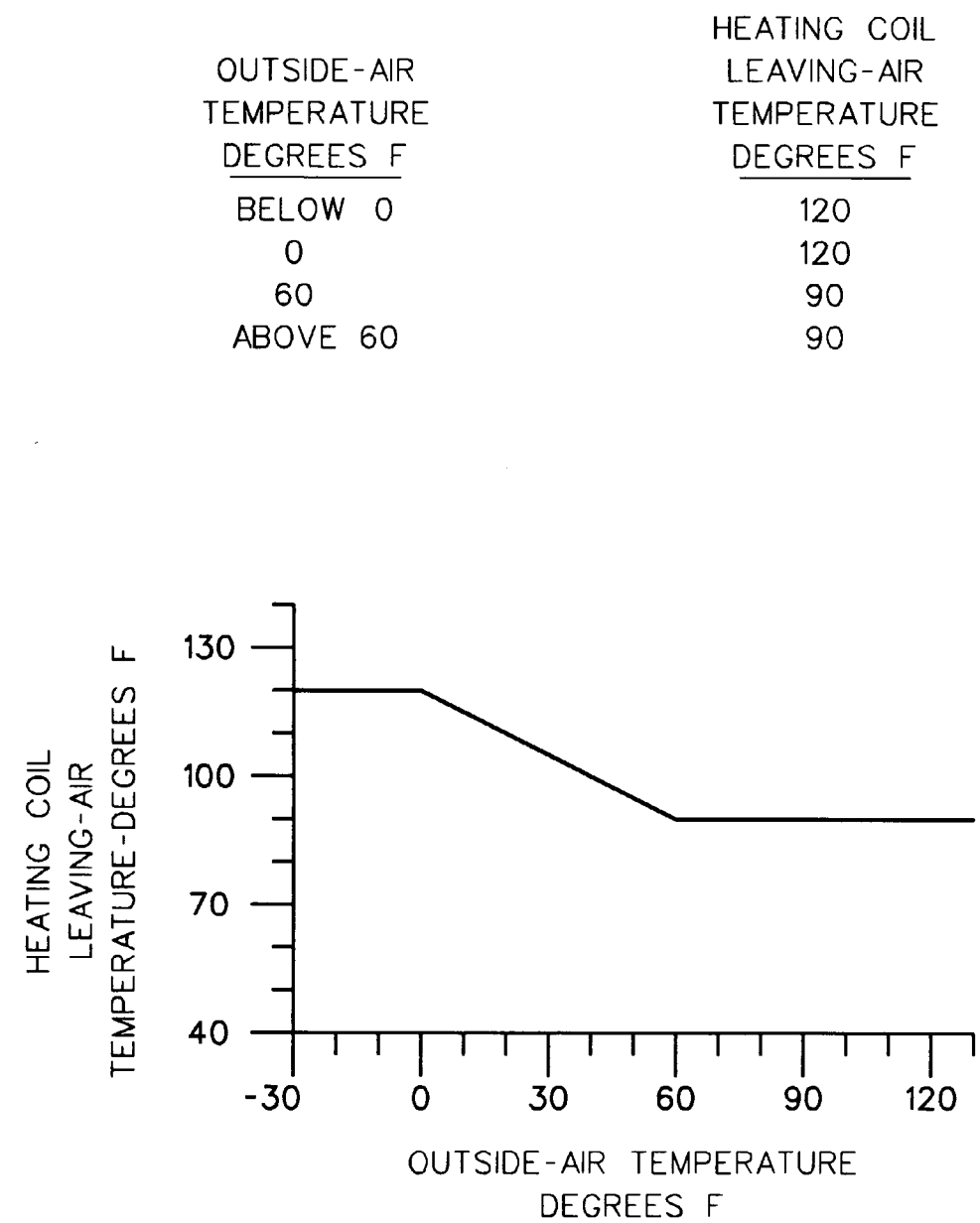


Figure 3-3. Heating-coil-temperature control loop scheduled from outside-air temperature.

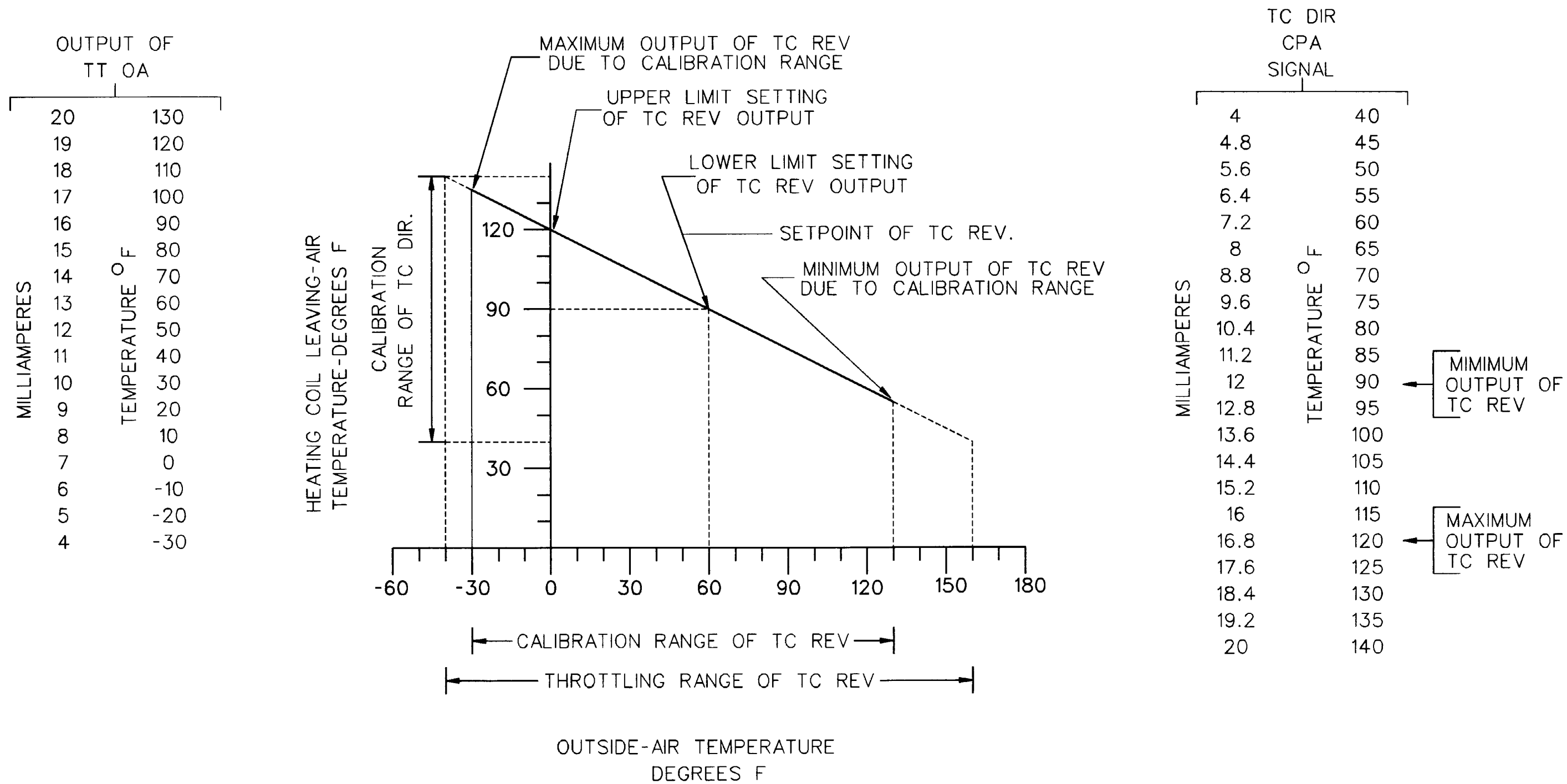


Figure 3-4. Outside-air-temperature controller input/output schedule.

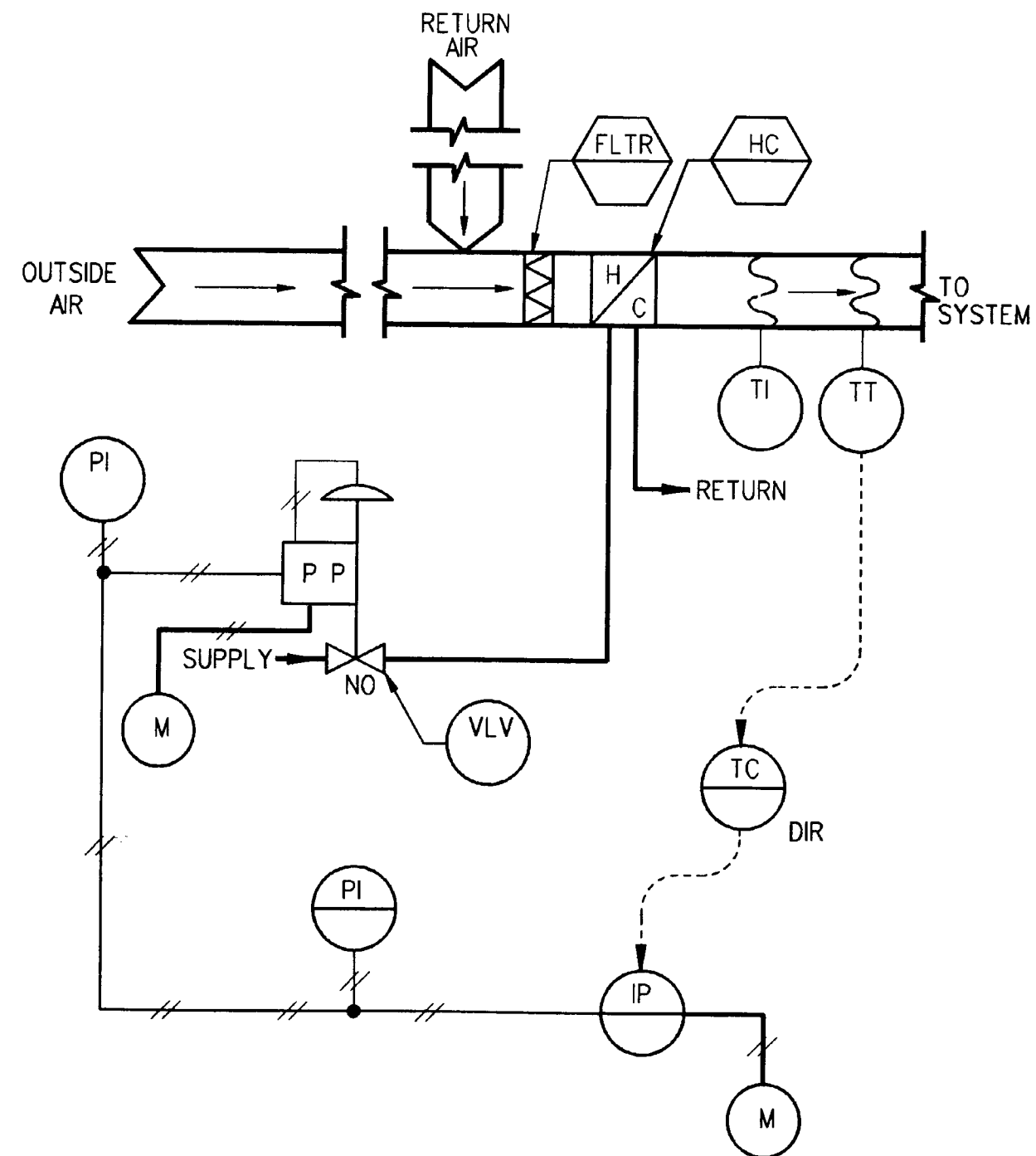


Figure 3-5. Heating-coil-temperature control loop with heating coil controlled at a constant temperature.

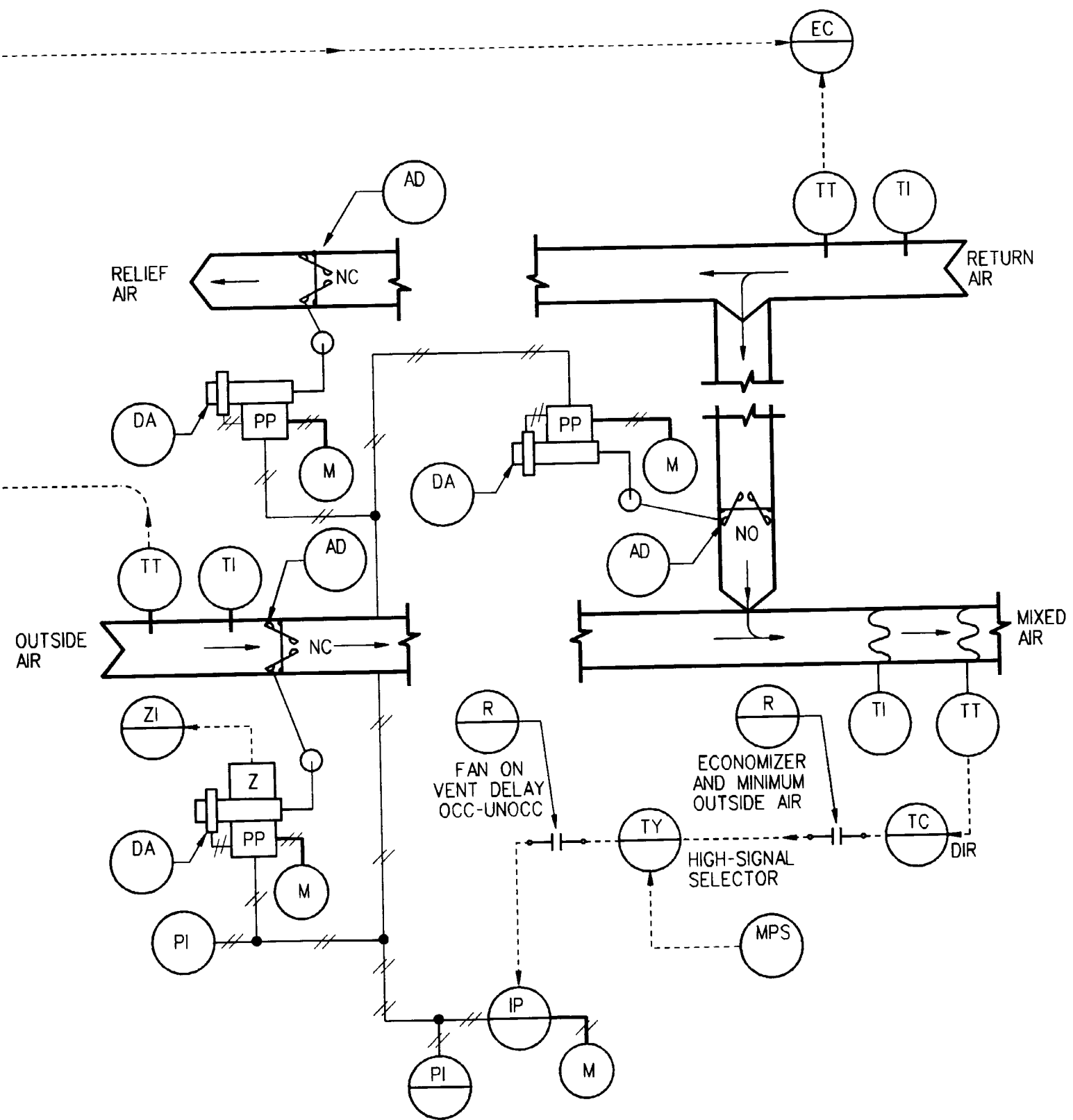


Figure 3-6. Mixed air-temperature and economized control loops.

OUTSIDE-AIR CONDITIONS	ADVANTAGEOUS OPERATING MODE	CONTROL-SYSTEM OPERATING MODE	REASONS
REGION A	ECONOMIZER	ECONOMIZER	ENTHALPY OA < ENTHALPY RA TEMPERATURE OA < TEMPERATURE RA
REGION B	MINIMUM OUTSIDE-AIR	MINIMUM OUTSIDE-AIR	ENTHALPY OA > ENTHALPY RA EVEN IF TEMPERATURE OA < TEMPERATURE RA
REGION C	MINIMUM OUTSIDE-AIR	MINIMUM OUTSIDE-AIR	ENTHALPY OA > ENTHALPY RA TEMPERATURE OA > TEMPERATURE RA
REGION D	ECONOMIZER	MINIMUM OUTSIDE-AIR	ENTHALPY OA < ENTHALPY RA EVEN IF TEMPERATURE OA > TEMPERATURE RA

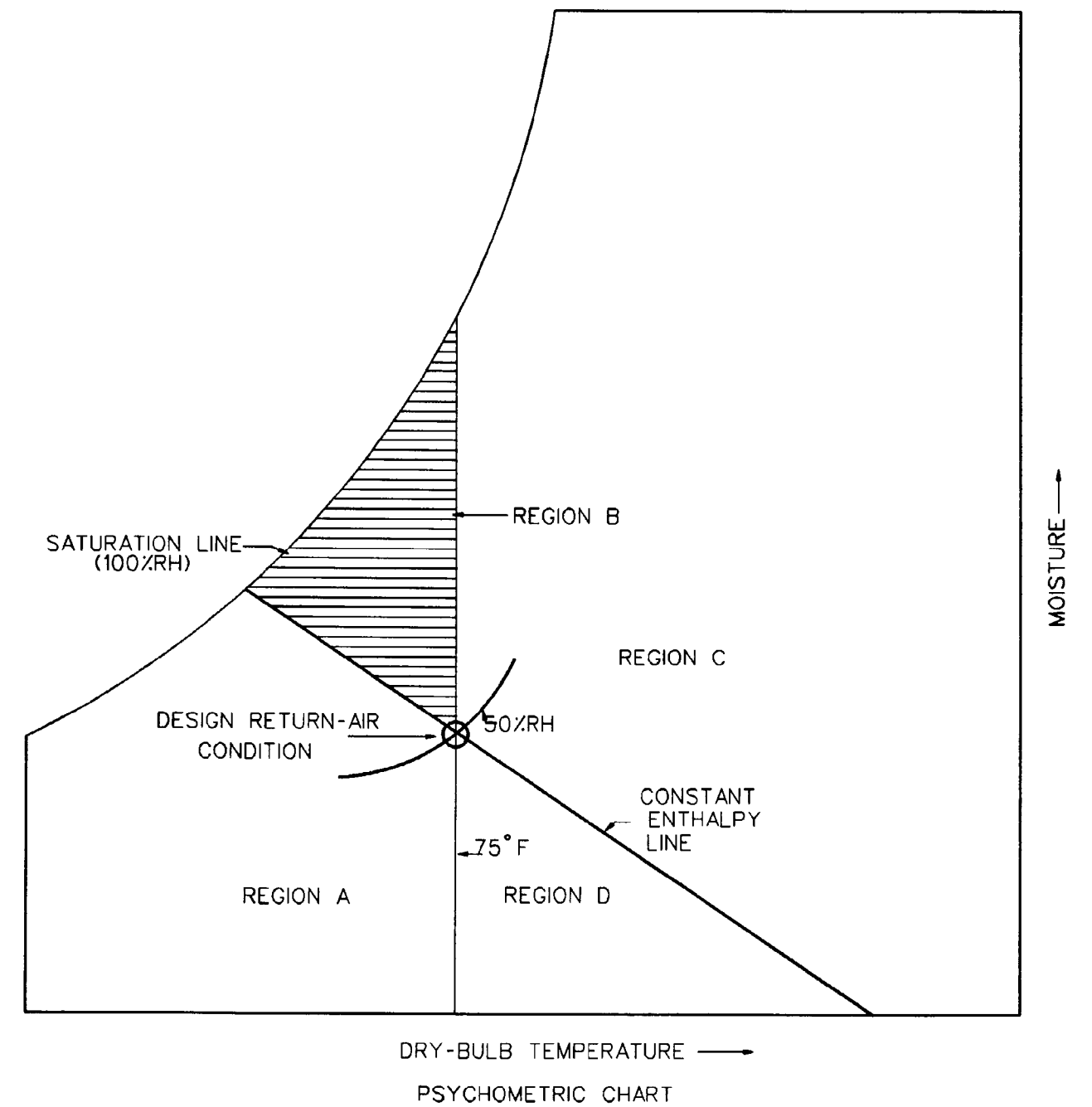


Figure 3-7. Design condition for economized-made operation.

OUTSIDE-AIR DRY-BULB TEMPERATURE BIN-DEGREES F	MIDPOINT OF TEMPERATURE BIN-DEGREES F	OUTSIDE-AIR COINCIDENT TEMPERATURE FOR BIN DEGREES F
100-104	102.5	77
95-99	97.5	77
90-94	92.5	77
85-89	87.5	74
80-84	82.5	72
75-79	77.5	70
70-74	72.5	68
65-69	67.5	63
60-64	62.5	58
55-59	57.5	53
50-54	52.5	48

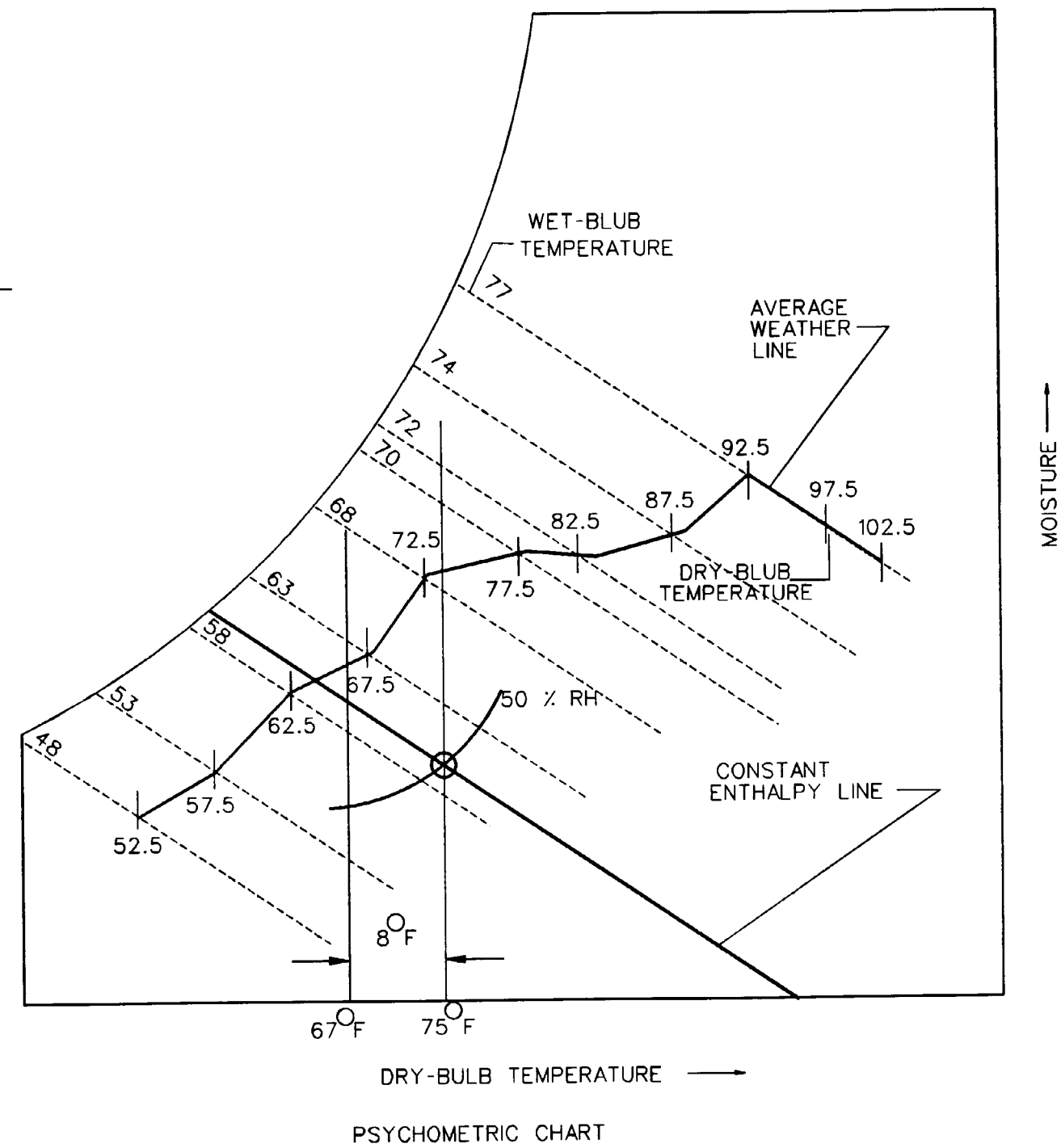


Figure 3-8. Selecting the economized switchover poing.

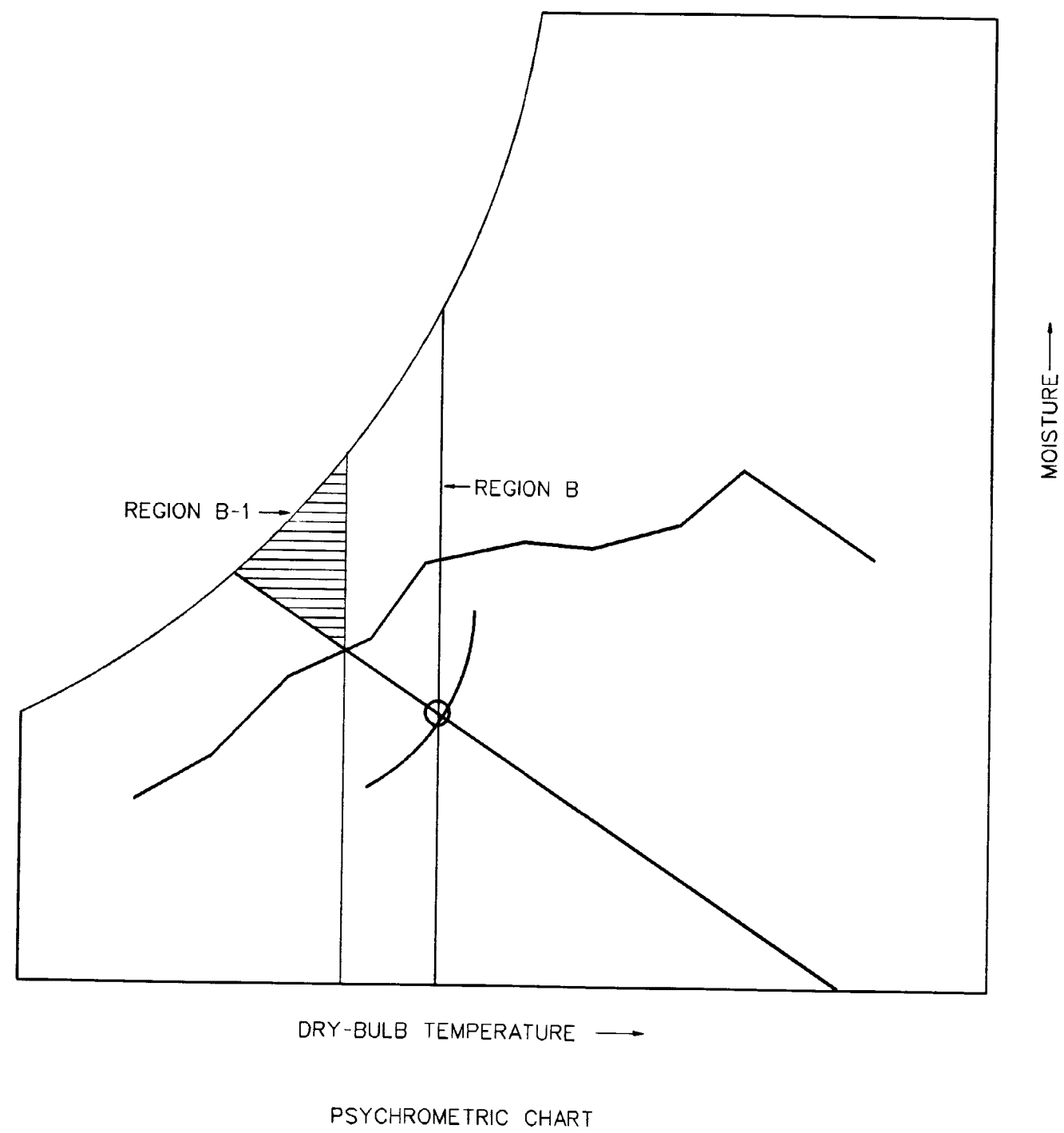


Figure 3-9. Effect on energy conservation of selecting the economized-switchover point.

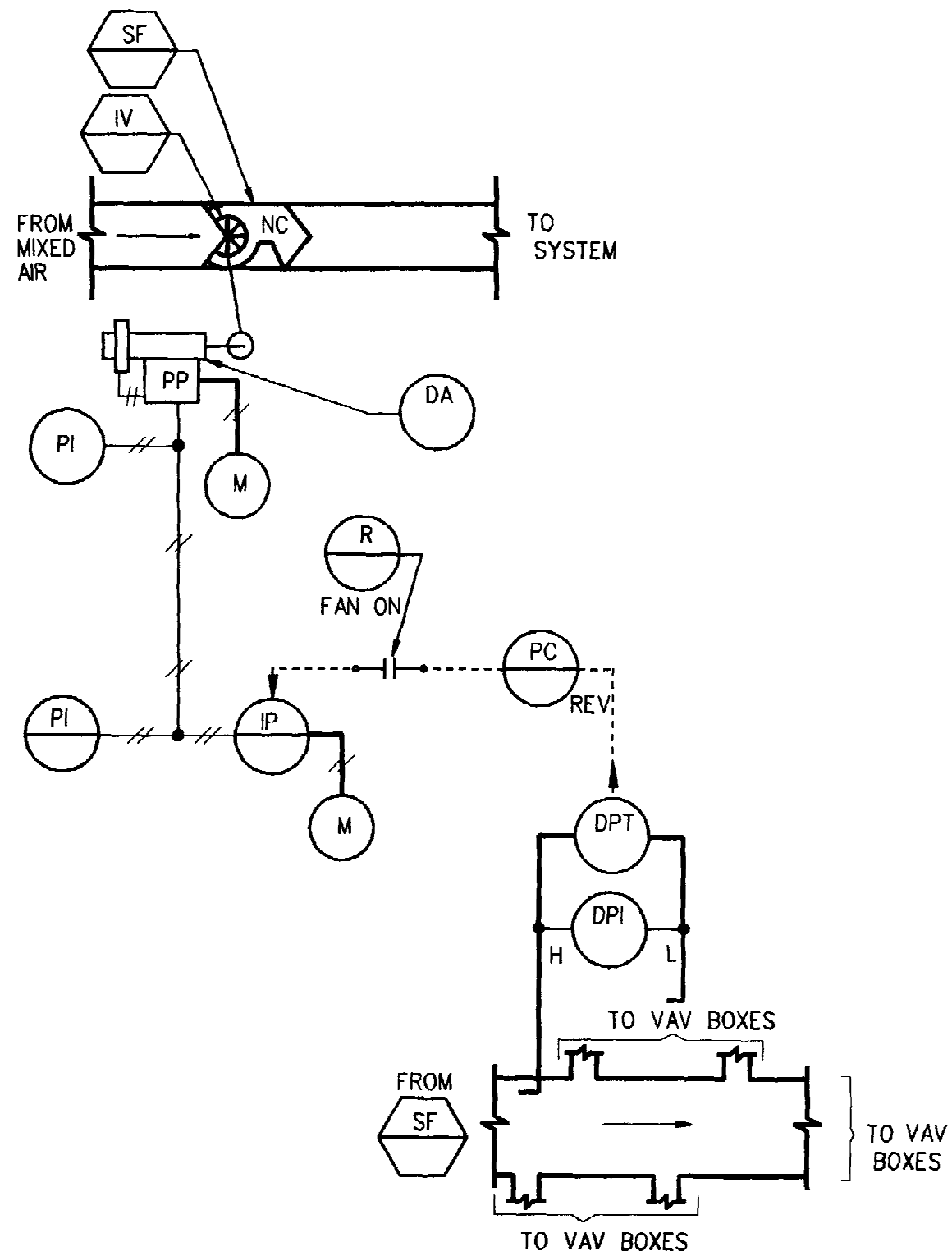


Figure 3-10. Supply-duct static-pressure control loop.

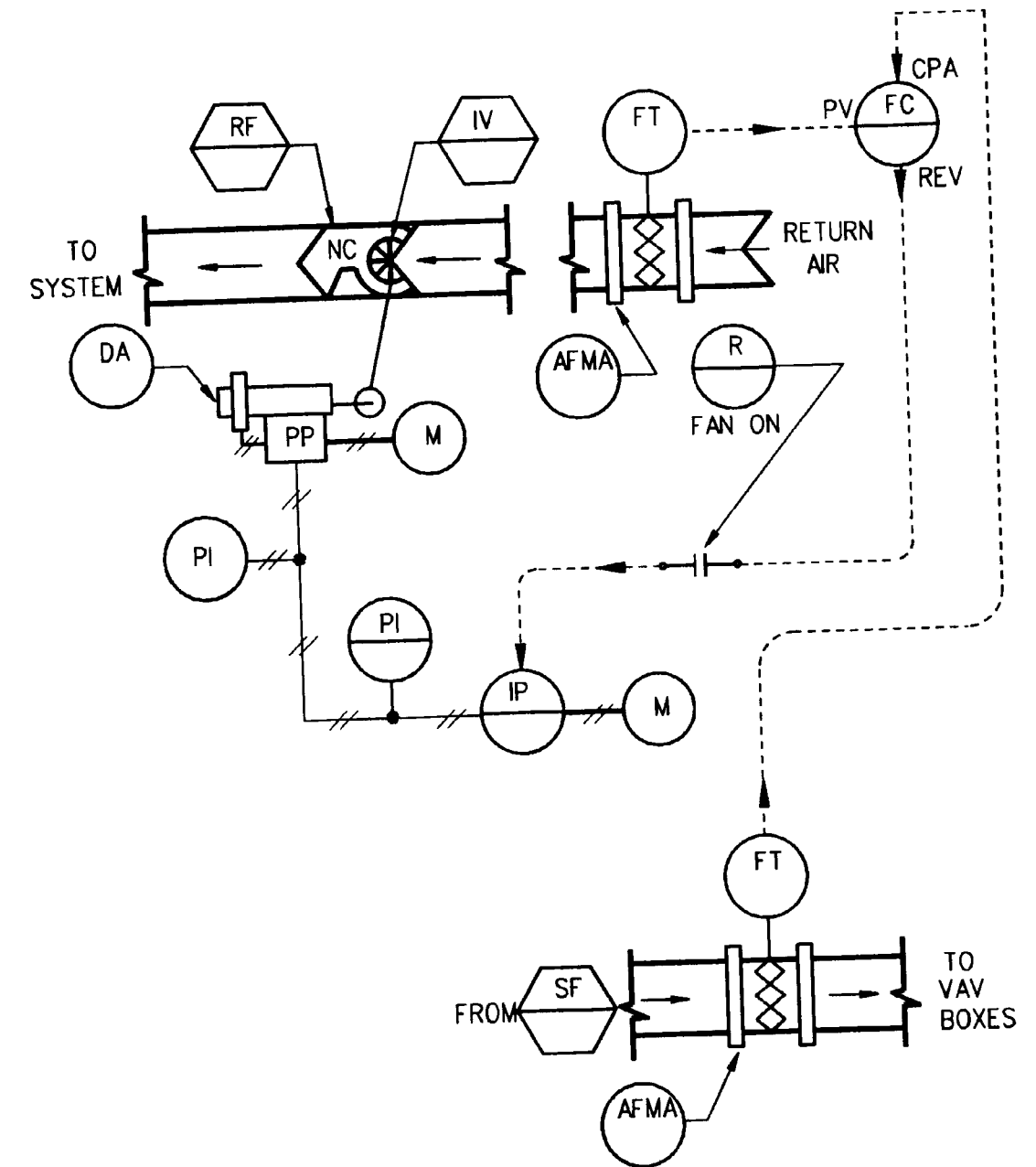


Figure 3-11. Return-fan-volume control loop.



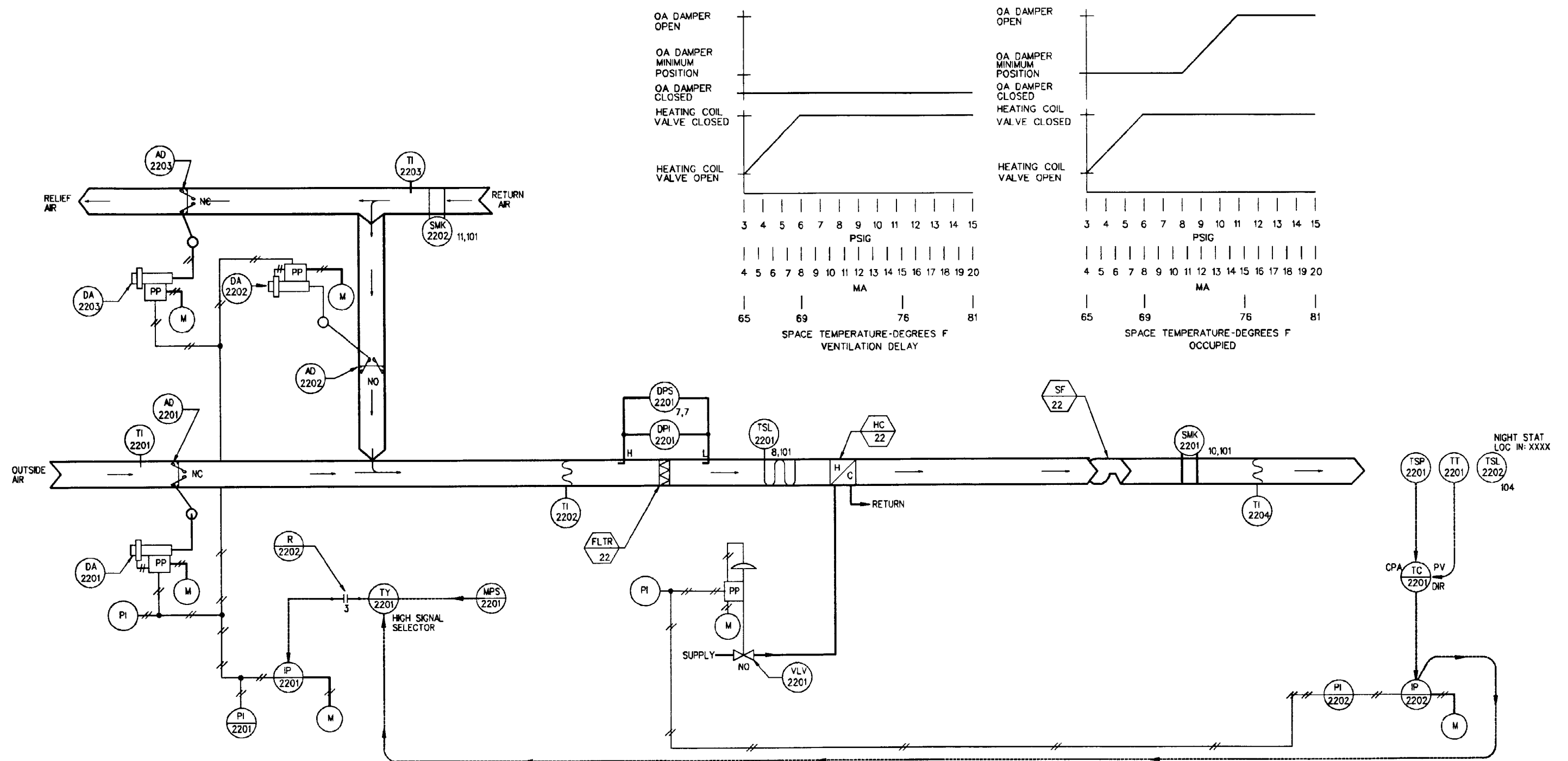


Figure 3-13. Typical schematic.

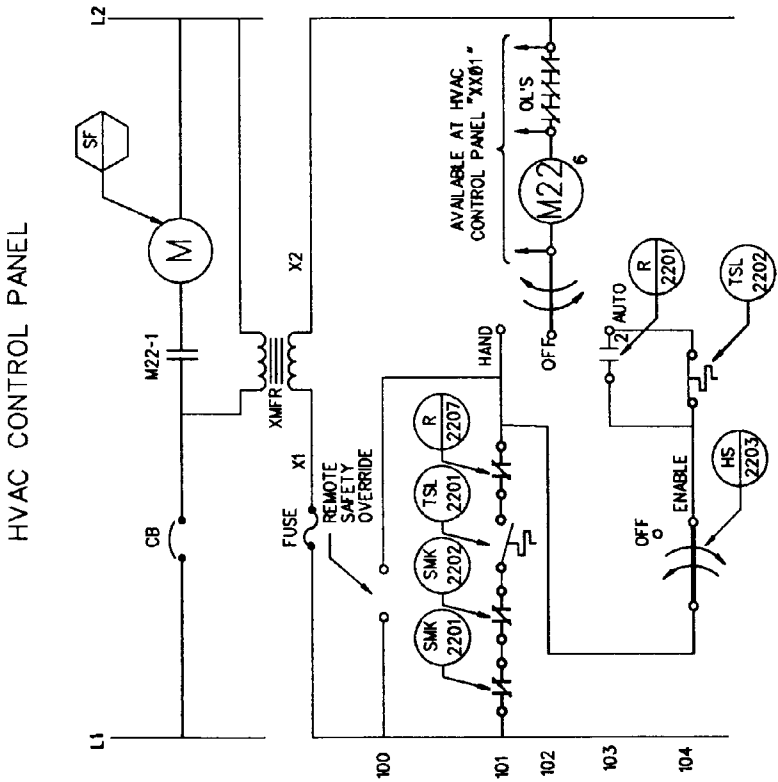
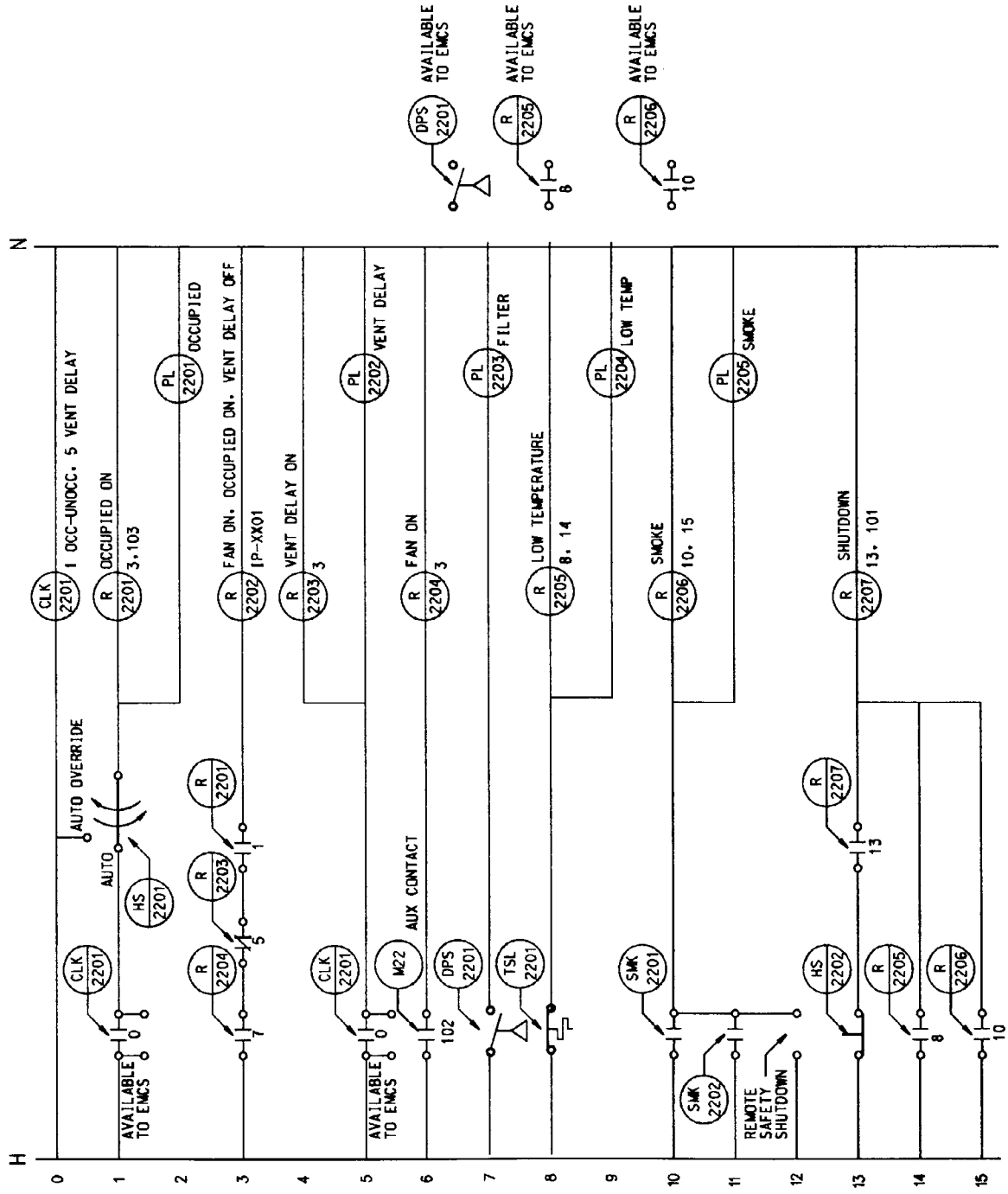


Figure 3-14. Typical ladder diagram.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
SPACE TEMPERATURE	DA-2201, 02, 03	DAMPER ACTUATOR	—	7-11 PSIG	—
	MPS-2201	MINIMUM-POSITION SWITCH	—	—	SET MIN DA CFM EQUALS 3000 CFM
	TSL-2201	LOW-TEMPERATURE PROTECTION THERMOSTAT	35°F	—	—
	VLV-2201	HEATING-COIL VALVE	—	3-6 PSIG	CV=7 CLOSE AGAINST 20 PSIG
	TC-2201	SPACE-TEMPERATURE CONTROLLER	68°F	50 TO 85°F	SET MAXIMUM LIMITS AVAILABLE TO OCCUPANT BY TSP-2201 AT 68 TO 72°F
	TT-2201	SPACE-TEMPERATURE TRANSMITTER	—	50 TO 85°F	—
SPACE LOW TEMPERATURE	TSL-2202	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
OCCUPIED MODE	CLK-2201 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS. OPEN: 1700 HRS M.T.W.TH.F	OPEN: SAT. SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-2201 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS. OPEN: 0800 HRS M.T.W.TH.F	

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS, AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 3-15. Typical equipment schedule.

Chapter 4

Standard HVAC Control Systems

4-1. General

a. The complete HVAC control-system design will include a series of drawings for each HVAC control system, based on the standard control systems presented in this chapter.

b. Variations to these control systems are shown in chapter 5.

c. Mr-delivery systems can be designed with or without return-air fans. For example, selected systems are shown with return-air fans. These HVAC systems are the multizone systems, the bypass multi-zone system, the dual-duet system, and the VAV system.

d. Where required, the control of a return fan can be incorporated into any air-delivery HVAC system shown in this manual by appropriately modifying the HVAC control-system drawings.

e. The use of supply-fan-only HVAC systems over supply/return-fan systems is based on the following: lower first cost, lower maintenance cost, lower energy costs, and less complex control systems. The advantages of the supply/return-fan system include positive control of the outside-air, return-air, and relief-air quantities under varying modes of operation. Return fans are sized smaller than the supply fan by the amount of air necessary for minimum outside air-space-pressurization air, and exhaust- makeup air.

f. In the case of the VAV system, the use of the return fan allows the minimum outside-air flow to remain constant when the control system is in the minimum-outside-air mode, and the delivery of the supply fan varies according to space-cooling demands. The control loop necessary to accomplish this is known as the return-fan-volume control loop. This loop is costly, complex, and, in some applications, difficult to control with stability.

g. The transmitter ranges shown are standard. These ranges match corresponding EMCS ranges where appropriate, and will not be changed.

4-2. Identification of control-system devices

Control-system devices will be numbered in accordance with the convention described for the unique identifiers shown in appendix A.

4-3. Project-specific drawings

To make the standard HVAC control-system drawings project-specific:

a. Add or delete loops as required.

b. Use a common time clock and common control panel where appropriate for HVAC systems (as described in chapter 5) unless the HVAC system is extended to EMCS.

c. If the project has EMCS, delete the time clock and replace with EMS contacts.

d. Incorporate system variations as required.

e. Replace "XX" in the drawing titles and unique identifiers with numbers specific to the project HVAC control system.

f. Modify HVAC control-panel interior-door layouts, back-panel layouts, and terminal-block layouts as required.

g. Parameters shown in the equipment list must be modified to make the standard HVAC control-system drawings project-specific.

h. Damper and valve position diagrams.

4-4. Space-temperature-controlled perimeter-radiation control system.

a. *Description of perimeter-radiation system.* This system consists of fin-tube radiation, a portion of the hydronic heating system. Figure 4-1 shows the schematic and ladder diagrams and the equipment schedule for this type of system.

b. *General sequence of operation.* A room thermostat controls a perimeter-radiation valve to maintain a set temperature. The following options are available:

(1) Two-position thermostat with two-position valve.

(2) Microprocessor-based thermostat which cycles a two-position valve during the occupied mode to maintain the programmed occupied-mode setpoint, and during the unoccupied mode to maintain the programmed unoccupied-mode setpoint.

(3) A modulating thermostat with a modulating valve.

c. *Detailed sequence of operation.*

(1) In two-position control, the contacts of room thermostat T-XX01 close on a rise in temperature to its setpoint, energizing normally-open valve LVLV-XX01, which closes. On a fall in temperature below its setpoint, the contacts of thermostat T-XX01 open, de-energizing valve VLV-XX01, which opens.

(2) In modulating control, thermostat T-XX01 modulates valve VLV-XX01 to maintain its setpoint.

4-5. Unit-heater temperature control system

a. *Description of unit-heater system.* This system consists of a unit with a heating coil and a fan to circulate air through a coil to provide heat to the space served. The heating coil is uncontrolled (no valve), but the fan is controlled. Unit heaters are used to provide heat in mechanical spaces and stairwells. Figure 4-2 includes the ladder diagram and equipment schedule for this type of system.

b. *General sequence of operation.* A unit thermostat cycles the unit-heater fan to maintain its setpoint temperature.

c. *Detailed sequence of operation.* Space thermostat TSL-XX01 has a manual "OFF-AUTO" switch. When the switch is indexed to "OFF", the unit-heater motor is de-energized. When the switch is indexed to "AUTO", the fan starts when the space temperature falls below the thermostat setpoint, and stops when the temperature rises to its setpoint.

4-6. Gas-fired infrared-heater control system

a. *Description of infrared-heater system.* This system consists of gas infrared heaters. Figure 4-3 shows the ladder diagram and equipment schedule for this system.

b. *General sequence of operation.* A thermostat cycles the infrared heater (or heaters) to maintain the programmed setpoint.

c. *Detailed sequence of operation.* A microprocessor-based room thermostat TuP-XX01 has an "AUTO-OFF" switch. When the thermostat switch is indexed to the "OFF" position, the infrared heater remains off. When the switch is indexed to the "AUTO" position, the infrared heater cycles during the occupied mode to maintain the programmed occupied temperature setpoint and during the unoccupied mode to maintain the programmed unoccupied temperature setpoint.

4-7. All-air small-package unitary system control system.

a. *Description of all-air small-package unitary system.* This system consists of a small self-contained air-handling unit provided with both heating and cooling equipment. Figure 4-4 shows the ladder diagram and equipment schedule for this system.

b. *General sequence of operation.* When indexed to "HEAT", a microprocessor-based room thermostat cycles the unit fan and heating equipment, to maintain the programmed temperature. When indexed to "COOL", the thermostat cycles the fan and cooling equipment, to maintain the programmed temperature.

c. *Detailed sequence of operation.* Microprocessor-based room thermostat TuP-XX01 is equipped with "HEAT-OFF-COOL" and "AUTO-ON" switches. It can be programmed to maintain separate occupied and unoccupied heating-mode and occupied cooling-mode temperatures. When the system switches are indexed to "HEAT" and "AUTO", the thermostat cycles the heating unit and the fan to maintain the programmed temperature; the cooling unit remains de-energized. When the thermostat is indexed to "COOL" and "AUTO", the thermostat cycles the cooling unit and the fan to maintain the programmed temperature; the heating unit remains de-energized. At the conclusion of the cooling-occupied mode, the system is de-energized and remains de-energized throughout the unoccupied mode. When indexed to "ON" the unit fan runs continuously. When the "HEAT-OFF-COOL" switch is indexed to "OFF", neither heating nor cooling can be energized.

4-8. Dual-temperature fan-coil unit control system

a. *Description of dual-temperature fan-coil system.* The system consists of a fan and a dual-temperature coil that is supplied with cold water during the cooling season and hot water during the heating season. Figure 4-5 shows the schematic and ladder diagrams and equipment schedule for this type of system.

b. *General sequence of operation.* A wall-mounted two-stage thermostat cycles the fan in winter to maintain its lower setpoint and in summer to maintain its higher setpoint. Fan speed is manually indexed by the room occupants.

c. *Detailed sequence of operation.*

(1) Wall-mounted two-stage thermostat TS-XX01 has two setpoints. The lower setpoint is a heating-mode setpoint, which, on a fall in temperature, cycles the fan to maintain the setpoint. The higher setpoint is a cooling-mode setpoint, which, on a rise in temperature, cycles the fan to maintain the setpoint.

(2) Strap-on aquastat TS-XX02, located on the return line downstream of the fan-coil 3-way valve, senses whether hot water or cold water is being supplied to the dual-temperature coil, and its snap-acting contacts determine which thermostat contact and setpoint will cycle the fan.

(3) Whenever the fan is energized, a three-way electric valve VLV-XX01 is also energized, to open the hydronic medium to the coil. Whenever the fan is deenergized, VLV-XX01 is also de-energized and closes the hydronic medium to the coil and opens it to coil bypass.

4-9. Control systems that require control panels

a. A HVAC control panel is required for each system that requires the control capabilities of the single-loop controller. The designer will show all the details of the standard HVAC control panel on the contract drawings. These details will describe the construction, mounting, and general arrangement of the standard HVAC control panel.

b. In addition, the contract drawings for each control system will show the specific interior-door arrangement, showing front and rear views, the back-panel layout, and the terminal-block layout for the control system, on the contract drawings.

4-10. Standard HVAC control panel

a. Figures 4-6A through 4-6I will provide the guidance for the HVAC control-panel arrangement for typical HVAC control systems.

b. The standard wall-mounted HVAC control panel (see figure 4-6A) is a standard enclosure of a specific size. This panel contains the single-loop controllers, IPs, power supply, indicators, gauges, function modules, relays, clocks, and terminal blocks, for connection to external devices and circuits and for connection to EMCS.

c. Figure 4-6B, section "A-A" through the panel, shows the general arrangement of the inside of the panel. The interior door, located behind the exterior key-locked door, is the mounting surface for controllers, receiver gauges, main air gauge, switches, and lights. The interior door has a continuous piano-type hinge to support the door and its devices. The back panel accommodates vertical and horizontal wiring ducts, and standard-size mounting rails. The mounting rails for the terminal blocks are elevated from the back panel to accommodate the wiring from the wiring ducts.

d. Figure 4-6C shows the general layout of the interior door for HVAC control panels. The front view shows that the panel's interior door will accommodate up to 6 controllers with receiver gauges in 2 rows of 3 controllers each. The main air gauge is on the right, and 5 pneumatic output indicators for IPs are located to the left of the main air gauge. The rear view shows rail-mounted IPs, connections to gauges, and a valve to access the main air for maintenance. In the event that additional space is required for function modules, such as loop drivers, they may be shown on this rail. The general arrangement shown will not be changed for the sake of symmetry. It is intended that this panel will accommodate one control system for an air-

delivery HVAC system and may also accommodate hydronic or other HVAC control systems. The switch and pilot-light matrix will have the devices arranged in the array shown.

e. Figure 4-6D shows the general arrangement of the back panel, which will have 2 vertical wiring ducts and 4 horizontal wiring ducts, with covers as shown. The mounting rail shown at the top of the panel will accommodate up to 15 relay bases, which will accept the wiring for plug-in relays. The relays will be placed from right to left in the numerical order of their unique identifiers. Below the relay mounting rail will be a horizontal wiring duct, and below this duct there will be 3 mounting rails and wiring ducts that will accommodate the terminal blocks to accept the control-system wiring. There will be a mounting rail for function modules, time clock, and power supply located below the terminal-block mounting rails and wiring ducts; loop drivers may also be mounted on this rail. A duplex receptacle, intended for maintenance use, will be mounted on the right side of the cabinet. The power conditioner and system fuses will be mounted on the left side of the cabinet. The system's dc power supply will be located to the left of the clock. The ac wiring will enter the wiring duct on the lower left of the panel and will be distributed vertically. The dc wiring will enter the wiring duct on the right and will also be distributed vertically.

f. The relative location assignments for 3 rows of numbered terminal-block locations are shown in figure 4-6E. Only the terminal blocks needed for the specific control-system loops will be included in the panel. Locations 1 through 70 in row 1 are dedicated to controller-loop wiring in groups of 10.

g. Figure 4-6F shows the standard wiring for a typical controller and for a controller used as an economizer controller. The left side of the figure shows that terminal 1 is always a shield terminal, and that terminals 2 and 3 are always for the transmitter connection. These terminals are designated as PV. Removal of a jumper between terminals 4 and 5 allows 4-20 ma PV signals to be connected to EMCS. Terminal 2 is connected to a dc-power terminal block and is jumpered to terminal 6 to supply power to the CPA; terminals 6 and 7 make the CPA available to EMCS. The signal returns of PV and CPA are connected to a dc-power terminal. Terminals 8 and 9 are wired to OUT. Removal of the jumper connecting terminals 8 and 9 will allow the controller to interface with an electric actuator rather than an IP. The controller, TC, powers its output loop. Terminal 10 is an additional shield terminal. The contacts shown as PV are wired as required for the application, without connection to terminal blocks. The right side of the figure shows that when the controller is used as an economizer controller, terminals 2 and 3 are connected to the return-air temperature transmitter, and terminals 6 and 7 are connected to the outside-air temperature transmitter. Terminals 8 and 9 contain the jumper for EMCS interface to the economizer logic.

h. Figure 4-6G shows the standard wiring for the HVAC-system's supply-fan and return-fan starters. The

"ENABLE-OFF" switch is connected to the supply fan only. If there are no smoke dampers, a jumper will be installed between terminals 185 and 186. One-hundred-percent outside-air systems with high-pressure fans will have end switches on the outside-air damper to insure that the damper is open before the fan starts. One-hundred-percent outside-air units with electric actuators will have end switches on the outside-air damper because of the inherently slower speed of the electric actuators in opening the damper. Under normal conditions, local-control switches for the supply-fan, return-fan, and exhaust-fan starters will be in the "AUTO" position. When the "ENABLE-OFF" switch is indexed to the "OFF" position, the return and exhaust fans will stop when the supply fan stops, through interlocked relay contacts in the "AUTO" position of the local starter control switch.

i. Figure 4-6H shows the wiring of exhaust fans when interlocked to other fans and also shows the wiring of pumps. The left side of the figure shows the exhaust-fan wiring. This wiring is similar to the return-fan wiring, except that a jumper is shown installed between terminals 205 and 206 because exhaust fans do not normally require the circuitry to prove that the exhaust dampers are open before the fan starts. If higher-pressure fans are used for exhaust fans, the exhaust dampers should have end switches and should be wired as a return fan, as shown in figure 4-6G. The right side of the figure shows the pump-starter wiring. A safety-shutdown circuit is not required. A jumper is shown installed between terminals 205 and 206. Each pump will have an "ENABLE-OFF" switch.

j. Figure 4-6I shows the HVAC control panel power wiring for ac and dc sources.

4-11. Central-plant steam hydronic-heating control system

a. *Description of hydronic-heating system.* This hydronic-heating system consists of a steam-to-hot-water converter that provides hot water to a primary pumping system. The primary pumping system supplies hot water to secondary pumping systems that provide hot water to separate zones of space-temperature control. Figures 4-7A through 4-7F show the system design for this type of heating system.

b. *General sequence of operation.*

(1) The primary-pumping system and the steam-to-hot-water converter operate continuously whenever the outside-air temperature is low enough for the building to require heating. When this occurs, an outside-air temperature controller starts the primary pump, enables the converter control system, and enables the secondary pumps to operate. The outside-air temperature controller raises the primary hot-water supply temperature as the outside-air temperature falls.

(2) The primary hot-water supply temperature controller maintains its setpoint by modulating the converter steam valve to maintain the scheduled primary hot-water supply temperature.

(3) During the occupied mode, the secondary hot-

water pumps run whenever the primary hot-water pump runs. Each zone-temperature controller modulates its zone-control valve to blend primary hot-water supply with secondary hot-water return in order to maintain the zone's space-temperature setpoint, which is adjustable by the zone occupant.

(4) During the unoccupied mode, the secondary hot-water pumps are cycled by the zone night thermostat to maintain the low-limit setpoint and to prevent freezing. During this mode, the space temperature controller setpoint is determined by an adjustment within the system's HVAC control panel.

c. *Detailed sequence of operation.*

(1) Outside-air temperature transmitter TT-XX01 signals outdoor-air temperature to temperature controller TC-XX01. On a fall in outside-air temperature to 60 degrees F, the process-variable (PV) contacts of TC-XX01 close to energize relays R-XX04 and R-XX05, and pilot light PL-XX02. The contacts of relay R-XX04 energize the primary hot-water pump, and the contacts of relay R-XX05 enable the secondary pumps. The auxiliary contacts of the primary-pump starter energize relay R-XX06, whose contacts then allow the primary-water-temperature control system to operate.

(2) On a rise in outside-air temperature to 62 degrees F, the PV contacts of controller TC-XX01 open to de-energize relay R-XX04 to stop the primary pump, and to de-energize relay R-XX05 to stop each secondary pump. The auxiliary contacts of the primary-pump starter open, de-energizing relay R-XX06, whose contacts then remove valve VLV-XX01 from control, causing it to close.

(3) Controller TC-XX01 raises the setpoint of primary hot-water supply temperature controller TC-XX02 as the outside-air temperature falls, and lowers the set-point as the outside-air temperature rises.

(4) Temperature transmitter TT-XX02 signals the primary hot-water supply temperature to temperature controller TC-XX02, which then maintains its setpoint by varying its signal to current-to-pneumatic transducer IP-XX01. The pneumatic signal from IP-XX01 modulates converter steam valve VLV-XX01 to maintain the primary-supply water-temperature setpoint of controller TC-XX02.

(5) Temperature transmitter TT-XX03 signals the zone space temperature to controller TC-XX03, which then maintains its setpoint by varying its current output signal to transducer IP-XX02. The pneumatic signal from IP-XX02 modulates secondary zone-control valve VLV-XX02. Zone-control valve VLV-XX02 mixes primary supply water with secondary return water to maintain the zone space-temperature setpoint. The temperature-control loops for the other secondary zones function identically.

(6) Throughout the occupied mode, the contacts of time clock CLK-XX01 are closed to energize relays R-XX01, R-XX02, and R-XX03, and to turn on pilot light PL-XX01. The contacts of relay R-XX01 connect temperature-setpoint device TSP-XX01 to allow manual adjustment of the setpoint of temperature controller TC-XX03. Relay R-XX02 provides the same function for

TSP-XX03 in adjustment of controller TC-XX04. Relay R-XX03 closes contacts in the starter-control circuits of the secondary pumps. The secondary-system pumps will start whenever the contacts of relay R-XX03 (occupied) and R-XX05 (heating) are closed in their respective pump-starter circuits.

(7) During the unoccupied mode, the contacts of time clock CLK-XX01 are open and de-energize relays R-XX01, R-XX02, and R-XX03; pilot light PL-XX01 turns off. The transfer of contacts of relay R-XX01 transfers the temperature-setpoint adjustment of TC-XX03 from TSP-XX01 to TSP-XX02; likewise, relay R-XX02 transfers the temperature-setpoint adjustment of TC-XX04 from TSP-XX03 to TSP-XX04. The contacts of relay R-XX03 open the secondary-pump starter circuits, to place the secondary pumps under the respective night thermostats TSL-XX01 and TSL-XX02. When the zone space temperature falls to 55 degrees F, the zone's secondary pump is energized and remains energized until the temperature rises to 57 degrees F.

4-12. Single-building hydronic-heating with hot water boiler control system

a. *Description of the hydronic-heating system.* This hydronic-heating system consists of a hot-water boiler that provides hot water to a primary-pumping system. The primary-pumping system supplies hot water to secondary-pumping systems that provide hot water to separate zones of space-temperature control. This control system varies the hot-water flow through the boiler. Therefore, it can be used only with boilers whose operation is not affected by flow variation. Figures 4-8A through 4-8F show the system design for this type of heating system.

b. *General Sequence of Operation.*

(1) The primary-pumping system and the boiler operate continuously whenever the outside-air temperature is low enough for the building to require heating. When this occurs, an outside-air temperature controller starts the primary pump, enables the boiler to function under its own control system to maintain a constant boiler-water temperature, and enables the secondary pump to operate. The outside-air temperature controller raises the primary hot-water supply temperature as the outside-air temperature falls.

(2) The primary hot-water supply temperature controller maintains its setpoint by modulating a valve to mix hot water from the boiler with return water from the primary-pumping system to maintain the scheduled primary hot-water supply temperature.

(3) During the occupied mode, the secondary hot-water pumps run whenever the primary hot-water pumps run. Each zone-temperature controller modulates its zone-control valve to blend primary hot-water supply with secondary hot-water return in order to maintain the zone's space-temperature setpoint, which is adjustable by the zone occupant.

(4) During the unoccupied mode, the secondary hot-water pumps are cycled by the zone's night thermostat to

maintain the low-limit setpoint and to prevent freezing. During this mode, the controller setpoint is determined by an adjustment within the system's HVAC control panel.

c. Detailed sequence of operation.

(1) Outside-air temperature transmitter TT-XX01 signals outdoor-air temperature to temperature controller TC-XX01. On a fall in outside-air temperature to 60 degrees F, the process-variable (PV) contacts of TC-XX01 close to energize relays R-XX04, R-XX05, and R-XX06 and pilot light PL-XX02. The contacts of relay R-XX04 energize the primary hot-water pump, the contacts of relay R-XX05 enable the secondary pumps, and the contacts of relay R-XX06 enable the boiler-control circuit.

(2) On a rise in outside-air temperature to 62 degrees F, the PV contacts of controller TC-XX01 open to de-energize relays R-XX04 to stop the primary pump, to de-energize relay R-XX05 to stop both secondary pumps, and to de-energize relay R-XX06 to disable the boiler-control circuit and to turn off pilot light PL-XX02.

(3) Controller TC-XX01 raises the setpoint of primary hot-water supply-temperature controller TC-XX02 as the outside-air temperature falls, and lowers the setpoint as the outside-air temperature rises.

(4) Temperature transmitter TT-XX02 signals the primary hot-water supply temperature to temperature controller TC-XX02, which then maintains its setpoint by varying its signal to current-to-pneumatic transducer IP-XX01. The pneumatic signal from IP-XX-1 modulates primary hot-water valve VLV-XX01 to mix boiler water and primary return water to maintain the primary-supply water-temperature setpoint of controller TC-XX02.

(5) Temperature transmitter TT-XX03 signals the zone space temperature to controller TC-XX03, which then maintains its setpoint by varying its current output signal to transducer IP-XX02. The pneumatic signal from IP-XX02 modulates secondary zone control valve VLV-XX02. Zone-control valve VLV-XX02 mixes primary supply water with secondary return water to maintain the zone space-temperature setpoint. The temperature-control loop for the other secondary zone functions identically.

(6) Throughout the occupied mode, the contacts of time clock CLK-XX01 are closed to energize relays R-XX01, R-XX02, and R-XX03, and to turn on pilot light PL-XX01. The contacts of relay R-XX01 connect temperature-setpoint device TSP-XX01 to allow manual adjustment of the setpoint of temperature controller TC-XX03. Relay R-XX02 provides the same function for TSP-XX03 in adjustment of controller TC-XX04. Relay R-XX03 closes contacts in the starter-control circuits of the secondary pumps. The secondary-system pumps will start whenever the contacts of relay R-XX03 (occupied) and R-XX05 (heating) are closed in their respective pump-starter circuits.

(7) During the unoccupied mode, the contacts of time clock CLK-XX01 are open, and de-energize relays R-XX01, R-XX02, and R-XX03; pilot light PL-XX01 turns off. The transfer of the contacts of relay R-XX01 transfer temperature-setpoint adjustment of TC-XX03 from TSP-

XX01 to TSP-XX02; likewise, relay R-XX02 transfers temperature-setpoint adjustment of TC-XX04 from TSP-XX03 to TSP-XX04. The contacts of relay R-XX03 open the secondary-pump starter circuits to place the secondary pumps under the respective night thermostats TSL-XX01 and TSL-XX02. When the zone space temperature falls to 55 degrees F, the zone's secondary pump is energized and remains energized until the temperature rises to 57 degrees F.

4-13. Central-plant high-temperature hot-water hydronic-heating control system

a. Description of the hydronic-heating system. This hydronic-heating system consists of a high-temperature hot-water converter that provides hot water to a primary pumping system. The primary pumping system supplies hot water to secondary pumping systems that provide hot water to separate zones of space-temperature control. Figures 4-9A through 4-9F show the system design for this type of heating system.

b. General Sequence of Operation.

(1) The primary pumping system and the high-temperature hot-water converter operate continuously whenever the outside-air temperature is low enough for the building to require heating. When this occurs, an outside-air-temperature controller starts the primary pump, enables the high-temperature hot-water converter's control system, and enables the secondary pumps to operate. The outside-air-temperature controller raises the primary hot-water supply temperature as the outside-air temperature falls.

(2) The primary hot-water supply-temperature controller maintains its setpoint by modulating the high-temperature hot-water converter valve to maintain the scheduled primary hot-water supply temperature.

(3) During the occupied mode, the secondary hot-water pumps run whenever the primary hot-water pump runs. Each zone-temperature controller modulates its zone control valve to blend water from the primary hot-water supply with secondary hot-water return in order to maintain the zone-space-temperature setpoint, which is adjustable by the zone occupant.

(4) During the unoccupied mode, the secondary hot-water pumps are cycled by the zone night thermostat to maintain the low-limit setpoint and to prevent freezing. During this mode, the controller setpoint is determined by an adjustment within the system's HVAC control panel.

c. Detailed Sequence of Operation.

(1) Outside-air temperature transmitter TT-XX01 signals outdoor-air temperature to temperature controller TC-XX01. On a fall in outside-air temperature to 60 degrees F, the process variable (PV) contacts of TC-XX01 close to energize relays R-XX04 and R-XX05, and to turn on pilot light PL-XX02. The contacts of relay R-XX04 energize the primary hot-water pump, and the contacts of relay R-XX05 enable the secondary pumps. The auxiliary contacts of the primary-pump starter energize relay R-XX06. The contacts of relay R-XX06 allow the primary-water temperature-control system to operate.

(2) On a rise in outside-air temperature to 62 degrees F, the PV contacts of controller TC-XX01 open to de-energize relay R-XX04 to stop the primary pump, and relay R-XX05 to stop both secondary pumps. The auxiliary contacts of the primary-pump starter open, de-energizing relay R-XX06. The contacts of relay R-XX06 remove valve VLV-XX01 from control, and it closes.

(3) Controller TC-XX01 raises the setpoint of primary hot-water supply-temperature controller TC-XX02 as the outside-air temperature falls, and lowers the setpoint as outside-air temperature rises.

(4) Temperature transmitter TT-XX02 signals the primary hot-water supply temperature to temperature controller TC-XX02. Controller TC-XX02 maintains its setpoint by varying its signal to current-to-pneumatic transducer IP-XX01. The pneumatic signal from IP-XX01 modulates high-temperature hot-water converter valve VLV-XX01 to maintain the primary-supply-water temperature setpoint of controller TC-XX02.

(5) Temperature transmitter TT-XX03 signals the zone space temperature to controller TC-XX03. Controller TC-XX03 maintains its setpoint by varying its current output signal to transducer IP-XX02. The pneumatic signal from IP-XX02 modulates secondary zone control valve VLV-XX02, which mixes primary supply water with secondary return water to maintain the zone space-temperature setpoint. The temperature-control loop for the other secondary zone functions identically.

(6) Throughout the occupied mode, the contacts of time clock CLK-XX01 are closed to energize relays R-XX01, R-XX02, and R-XX03, and to turn on pilot light PL-XX01. The contacts of relay R-XX01 connect temperature-setpoint device TSP-XX01 to allow manual adjustment of the setpoint of temperature controller TC-XX03. Relay R-XX02 provides the same function for TSP-XX03 in adjustment of controller TC-XX04. Relay R-XX03 closes contacts in the starter-control circuits of the secondary pumps. The secondary-system pumps will start whenever the contacts of relay R-XX03 (occupied) and R-XX05 (heating) are closed in their respective pump-starter circuits.

(7) During the unoccupied mode, the contacts of time clock CLK-XX01 are open and de-energize relays R-XX01 R-XX02 and R-XX03 and pilot light PL-XX01 turns off. The transfer of the contacts of relay R-XX01 transfers the temperature setpoint adjustment of TC-XX03 from TSP-XX01 to TSP-XX02. The transfer of the contacts of relay R-XX02 transfers TC-XX04 temperature setpoint adjustment from TSP-XX03 to TSP-XX04. The contacts of relay R-XX03 open the secondary-pump starter circuits to place the secondary pumps under the respective night thermostats TSL-XX01 and TSL-XX02. When the zone space temperature falls to 55 degrees F, the zone secondary pump is energized and remains energized until the temperature rises to 57 degrees F.

4-14. Central-plant steam dual-temperature hydronic control system

a. Description of the hydronic system. This hydronic heating and cooling system consists of hot water from a

steam converter, chilled water from a central plant, and related pumping systems. Figures 4-10A through F-10F show the system design.

b. General sequence of operation.

(1) Heating and cooling modes are manually selected.

(2) When the system is in the heating mode, the pumping system and the converter operate continuously whenever the outside-air temperature is low enough for the building to require heating. When this occurs, an outside-air temperature controller starts the system pump, and the converter control is activated. The outside-air temperature controller raises the hot-water supply temperature as the outside-air temperature falls.

(3) The hot-water-supply temperature controller maintains its setpoint by modulating the converter valve to maintain the scheduled temperature.

(4) When the system is indexed to cooling, the converter valve closes. The pump continues to run for cool-down and when the return-water temperature falls to 85 degrees F, the changeover valves transfer the water flow from the converter to the central-plant chilled-water system.

(5) As long as the heating-cooling switch is indexed to cooling, the pump will be energized during the occupied mode and de-energized during the unoccupied mode.

c. Detailed sequence of operation.

(1) Manual switch HS-XX02 provides for indexing the system to the heating or the cooling mode.

(2) When heating-cooling switch HS-XX02 is indexed from heating to cooling, relay R-XX02 is de-energized, and relay R-XX05 is energized. Contacts of relay R-XX05 open, removing control from the converter valve, which then closes. Through the normally-closed contacts of relay R-XX02 and the normally-open contacts of relay R-XX06, pump relay R-XX07 is energized and the pump runs to distribute the hot water in order to reduce its temperature. When the return-water temperature falls to the set-point of TSL-XX01, the solenoid-actuated pneumatic valve EP-XX01 and relay R-XX06 are energized, and cooling pilot light PL-XX03 is turned on. Through EP-XX01, changeover valves VLV-XX02 and VLV-XX03 stop the flow to and from the converter, and open the system to the central-plant chilled-water system. The normally-closed contacts of relay R-XX06 (line 13) open to stop the pump, but the normally-open contacts of that relay (line 12) close. If occupied relay R-XX01 is energized, the pump continues to run.

(3) Throughout the cooling mode, pump relay R-XX07, through the normally-closed contacts of relay R-XX02 and the normally-open contacts of relay R-XX06, is energized during the occupied mode and de-energized during the unoccupied mode by the contacts of relay R-XX01.

(4) When heating-cooling switch HS-XX02 is indexed from cooling to heating, relays R-XX05 and R-XX06 and solenoid-actuated pneumatic valve EP-XX01 are de-energized cooling pilot light PL-XX03 is turned off, and relay R-XX02 is energized. When EP-XX01 is de-energized, valves VLV-XX02 and VLV-XX03 open the system to the converter and close it to the central-point chilled-water system.

(5) On a fall in outside-air temperature to the setpoint of the PV contacts of controller TC-XX01, relay R-XX04 is energized and heating pilot light PL-XX02 is turned on. The contacts of relay R-XX04 (line 11), which are closed throughout the heating mode, energize relay R-XX07. The contacts of relay R-XX07 energize the system pump. Pump-starter auxiliary contacts, through the normally-closed contacts of relay R-XX05 (line 4) energize relay R-XX03, and the contacts of relay R-XX03 connect the output of temperature controller TC-XX02 to current-to-pneumatic transducer IP-XX01. The transducer output modulates hot-water converter valve VLV-XX01. On a rise in outdoor-air temperature to 62 degrees F, the PV contacts of controller TC-XX01 open, and relay R-XX04 is de-energized, deenergizing relay R-XX07 and stopping the pump. Pump-starter auxiliary contacts remove the converter valve from control, and the converter valve closes.

(6) Outside-air controller TC-XX01 raises the setpoint of hot-water-supply temperature controller TC-XX02 as the outside-air temperature falls and lowers the setpoint as the outside-air temperature rises.

(7) Temperature controller TC-XX02, with its temperature transmitter in the hot-water supply piping, through current-to-pneumatic transducer IP-XX01, modulates high-temperature hot-water converter valve VLV-XX01 to maintain the supply-water-temperature setpoint of controller TC-XX02.

4-15. Central-plant high-temperature hot-water dual-temperature hydronic control system

a. *Description of the hydronic system.* This hydronic heating and cooling system consists of hot water from a high-temperature hot-water converter, chilled water from a central plant, and related pumping systems. Figures 4-11A through 4-11F show the system design.

b. *General sequence of operation.*

(1) Heating and cooling modes are manually selected.

(2) When the system is in the heating mode, the pumping system and the high-temperature hot-water converter operate continuously whenever the outside-air temperature is low enough for the building to require heating. When this occurs, an outside-air temperature controller starts the system pump, and the converter is under control. The outside-air temperature controller raises the hot-water supply temperature as the outside-air temperature falls.

(3) The hot-water-supply temperature controller maintains its setpoint by modulating the high-temperature hot-water converter valve to maintain the scheduled hot-water-supply temperature setpoint.

(4) When the system heating-cooling switch is indexed to cooling, the converter valve closes. The pump continues to run for cooldown of the system water. When the return-water temperature falls to 85 degrees F, the changeover valves transfer the water flow from the converter to the central-plant chilled-water system.

(5) As long as the switch HS-XX02 is indexed to cooling, the pump will be energized during the occupied mode and de-energized during the unoccupied mode.

c. *Detailed sequence of operation.*

(1) Manual switch HS-XX02 provides for indexing the system to the heating or the cooling mode.

(2) When heating-cooling switch HS-XX02 is indexed from heating to cooling, relay R-XX02 is de-energized and relay R-XX05 is energized. Contacts of relay R-XX05 open to de-energize relay R-XX03 and remove control from the converter valve, which then closes. Through the normally-closed contacts of relay R-XX02 and the normally-open contacts of relay R-XX06, pump relay R-XX07 is energized and the pump runs to distribute the hot water to reduce its temperature. When the return-water temperature falls to the setpoint of TSL-XX01, solenoid-actuated pneumatic valve EP-XX01 and relay R-XX06 are energized, and cooling pilot light PL-XX03 is turned on. Through EP-XX01 changeover valves, VLV-XX02 and VLV-XX03 stop the flow to and from the converter, and open the system to the central-plant chilled-water system.

(3) Throughout the cooling mode, pump relay R-XX07, through the normally-closed contacts of relay R-XX02 and the normally-open contacts of relay R-XX06, is energized during the occupied mode and de-energized during the unoccupied mode by the contacts of relay R-XX01.

(4) When heating-cooling switch HS-XX02 is indexed from cooling to heating, relays R-XX05 and R-XX06 and solenoid-actuated pneumatic valve EP-XX01 are de-energized, cooling pilot light PL-XX03 is turned off, and relay R-XX02 is energized. When EP-XX01 is de-energized, valves VLV-XX02 and VLV-XX03 open the system to the converter and close it to the central-plant chilled-water system.

(5) On a fall in outside-air temperature to the setpoint of the PV contacts of controller TC-XX01, relay R-XX04 is energized and heating pilot light PL-XX02 is turned on. The contacts of relay R-XX04 (line 11), which are closed throughout the heating mode, energize relay R-XX07. The contacts of relay R-XX07 energize the system pump. Pump-starter auxiliary contacts, through the normally-closed contacts of relay R-XX05 (line 4) energize relay R-XX03 and the contacts of relay R-XX03 connect the output of temperature controller TC-XX02 to current-to-pneumatic transducer IP-XX01. The transducer output modulates hot-water converter valve VLV-XX01. On a rise in outdoor-air temperature to 62 degrees F, the PV contacts of controller TC-XX01 open, and relay R-XX04 is de-energized, de-energizing relay R-XX07 and stopping the pump. Pump-starter auxiliary contacts remove the converter valve from control, and the converter valve closes.

(6) Outside-air controller TC-XX01 raises the setpoint of hot-water-supply temperature controller TC-XX02 as the outside-air temperature falls and lowers the setpoint as the outside-air temperature rises.

(7) Temperature controller TT-XX02, with its temperature transmitter in the hot-water supply piping, through current-to-pneumatic transducer IP-XX01, modulates high-temperature hot-water converter valve VLV-XX01 to maintain the supply-water-temperature

setpoint of controller TC-XX02.

4-16. Single-building dual-temperature hydronic control system

a. *Description of the hydronic system.* This hydronic heating and cooling system consists of a boiler, chiller, pump and distribution piping. The system varies the hot-water flow through the boiler. Therefore, it can be used only with boilers that are not sensitive to flow variation. Figures 4-12A through 4-12F illustrate the system design for this type of hydronic system.

b. *General sequence of operation.*

(1) Heating and cooling modes are manually selected at the control panel.

(2) When the system is indexed to heating, the boiler and pump operate continuously whenever the outside-air temperature is low enough for the building to require heating. When this occurs, the system boiler is started and the system pump is energized. The boiler functions under its own control system to maintain a constant boiler-water temperature. As the outside-air temperature falls the supply-water temperature is raised.

(3) The control system modulates a three-way valve to mix supply and return hot water to maintain the scheduled hot-water supply temperature setpoint.

(4) When the system is indexed from the heating mode to the cooling mode, the boiler is shut down. The pump continues to run to dissipate the heat from the piping system and the boiler until the return-water temperature drops below the setpoint of the return-water thermostat. The changeover valves then close to the boiler and open to the chiller.

(5) When the system is indexed to cooling and changeover has occurred, the chiller and pump are energized during the occupied mode. At the conclusion of the occupied mode, the chiller is de-energized but the pump continues to circulate water for a period of time while the chiller completes its shutdown cycle, and then the pump stops.

(6) When the system is indexed from cooling to heating, the chiller enters its shutdown cycle and the pump continues to circulate water through the chiller for a period of time while the chiller completes its shutdown cycle. The changeover valves then close to the chiller and open to the boiler.

c. *Detailed sequence of operation.*

(1) Heating-cooling switch HS-XX02 is manually operated to index the dual-temperature hydronic system to heating or to cooling.

(2) When switch HS-XX02 is indexed from heating to cooling, relays R-XX03, R-XX04, and R-XX05 are de-energized, heating pilot light PL-XX02 is turned off, and relays R-XX06 and R-XX07 are energized. The contacts of relay R-XX04 interrupt control of valve VLV-XX01 until the system's heating-cooling switch is returned to the heating mode. The contacts of relay R-XX05 open to shut down the boiler. The normally-closed contacts of R-XX03 on line 14 close, and the normally-closed contacts of relay R-XX06 on line 13 open, transferring the control of pump

relay R-XX09 from heating to cooling. The normally-open contacts of R-XX03 on line 17 open to reset time-delay relay TDR-XX01. Relay R-XX07 is energized, and the contacts of relay R-XX07 on line 18 close to energize time-delay relay TDR-XX01 and restart the time-delay period. The contacts of TDR-XX01 on line 19 close, energizing relays R-XX10 and R-XX11 for the length of time set on TDR-XX01. The contacts of relay R-XX10 on line 11 open to prevent chiller relay R-XX08 from being energized for the length of time set on time delay relay TDR-XX01. When the dual-temperature water-return temperature falls to the setpoint of return-water thermostat TSL-XX01 its contacts on line 10 close to energize EP-XX01. Valves VLV-XX02 and VLV-XX03 shut off the system supply and return water to the boiler and open the supply and return water to the chiller. The occupied/unoccupied contacts of time clock CLK-XX01 energize relay R-XX01 and turn on occupied pilot light PL-XX01. The contacts of relay R-XX01 on line 11 energize relay R-XX08, which energizes the chiller. The contacts of R-XX01 on line 14 energize relay R-XX09, which energizes the system pump.

(3) Five minutes before the end of the occupied mode, the time-delay reset contacts of time clock CLK-XX01 close, energizing relay R-XX02. The contacts of relay R-XX02 on line 16 keep the system pump energized until fifteen minutes after the unoccupied mode has begun. When the normally-closed contacts of relay R-XX02 (line 18) open, they reset time-delay relay TDR-XX01 on line 17. Ten minutes after the contacts of relay R-XX02 (line 18) close, they energize relays R-XX10 and R-XX11. The contacts of relay R-XX10 on line 15 close, and the pump runs for the additional time set on TDR-XX01.

(4) When heating-cooling switch HS-XX02 is indexed from cooling to heating, the chiller is de-energized through the contacts of relay R-XX08 on line 300. Relay R-XX03 is energized and relays R-XX06 and R-XX07 are de-energized. The contacts of relay R-XX06 on line 13 close, the contacts of relay R-XX03 on line 14 open, and pump control relay R-XX09 switches from the cooling to the heating mode of control. The contacts of relay R-XX07 on line 18 open to reset time-delay relay TDR-XX01. The contacts of relay R-XX03 on line 17 reset TDR-XX01. The instantaneous-close, time-out-to-open contacts of TDR-XX01 on line 19 energize relays R-XX10 and R-XX11 for the length of time set on TDR-XX01. The contacts of relay R-XX11 on line 11 close to keep EP-XX01 energized. When EP-XX01 is energized, the changeover valves remain open to the chiller for chiller shutdown. The contacts of relay R-XX10 on line 15 keep the pump operating. At the conclusion of the time delay, the pump is placed under control of outside-air temperature via the PV contacts of controller TC-XX01. EP-XX01 is deenergized and valves VLV-XX02 and VLV-XX03 open to the boiler and close to the chiller.

(5) When the system is indexed to heating, on a fall in outside-air temperature to the setpoint of the PV contacts of temperature controller TC-XX01, the contacts close, energizing relay R-XX05 and lighting pilot light PL-

XX02. One set of contacts of R-XX05 energizes the boiler control circuit, and the other set of contacts through a set of normally-dosed contacts of relay R-XX06 (energized during the cooling season), energizes relay R-XX09. A set of the contacts of relay R-XX09 energizes the system pump. The auxiliary contacts of the pump-motor starter, through another set of normally-closed contacts of relay R-XX06, energizes relay R-XX04. Relay R-XX04 places valve VLV-XX01 under the control of the dual-water supply temperature controller TC-XX02 whenever the pump runs during the heating season.

(6) Dual-temperature supply water-temperature transmitter TT-XX02 signals the supply temperature to temperature controller TC-XX02. Controller TC-XX02 maintains its setpoint by varying its signal to current-to-pneumatic transducer IP-XX01. The pneumatic output from IP-XX01 modulates three-way valve VLV-XX01 to mix boiler water and return water to maintain the temperature setpoint of controller TC-XX02. Outside-air temperature transmitter TT-XX01 signals the outside-air temperature to temperature controller TC-XX01. As the outside-air temperature falls, TC-XX01 raises the set-point of controller TC-XX02.

4-17. Heating-and-ventilating control system

a. Description of the heating-ventilating system. This air-handling system consists of a supply fan, outside-air, return-air and relief-air dampers, a filter, and a heating coil. Figures 4-13A through 4-13F show the design for this type of air-handling system.

b. General sequence of operation.

(1) *Supply fan off* When the fan is off, the outside-air and relief-air dampers are closed and the return-air damper is open. The heating-coil valve is under the control of the space temperature controller.

(2) *Supply-fan operating.* When the supply fan is on, the control dampers and the heating-coil valve are operated as required by the system's mode of operation. The control dampers are either positioned for full recirculation of air, positioned to introduce minimum outside air, or modulated in sequence with the heating coil to maintain space temperature. The heating coil is modulated by the space-temperature controller.

(3) *Control of the supply fan.* Unless the fan is stopped as the result of a safety shutdown, it is on or off as required by the control system's mode of operation.

(4) *Safety shutdown of the fans.* The control system shuts down the fans if there is a low-temperature condition or smoke is detected.

(5) *Low-temperature detection.* On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply fan. To restart the fan, the thermostat and the control panel must be manually reset.

(6) *Smoke detection.* Duct smoke detectors in the supply and return air stop the supply fan whenever either detects the presence of smoke. To restart the fan, the smoke detectors and control panel must be manually reset.

(7) *Filter condition.* Filter condition is monitored by a pressure gauge and a differential-pressure switch. On

a rise in pressure drop across the filter to the switch set-point, the switch turns on a pilot light.

(8) *Unoccupied mode of operation.* Throughout the unoccupied mode, the outside-air and relief-air dampers remain closed and the return-air damper remains open. The supply fan is cycled by the system's night thermostat to maintain its low-limit space-temperature setpoint.

(9) *Ventilation-delay mode of operation.* During the ventilation-delay mode, the dampers remain as they were throughout the unoccupied mode and the supply fan runs continuously. Until the ventilation-delay mode ends, the HVAC system circulates return air to bring the building to comfort conditions, using a minimum of energy.

(10) *Occupied mode of operation.* The supply fan runs continuously. The heating-coil valve and control dampers are modulated, with a deadband between them, by the space temperature controller.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode under which the system operates. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay R-XX03 and turning on pilot light PL-XX02. The normally-closed contacts of relay R-XX03 open, to prevent relay R-XX02 from being energized. The normally-open contacts of relay R-XX02 prevent signals from reaching current-to-pneumatic transducer IP-XX01. The dampers remain in their normal positions, with outside-air and relief-air dampers closed and return-air damper open.

(2) When the occupied contacts of time clock CLK-XX01 close, relay R-XX01 is energized and pilot light PL-XX01 is turned on. Contacts of relay R-XX01 energize the supply fan. The auxiliary contacts of the supply-fan starter energize relay R-XX04.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode, relay R-XX03 is de-energized and pilot light PL-XX02 is turned off. With the now closed but normally-open contacts of energized relays R-XX01 and R-XX04, the normally-closed contacts of relay R-XX03 energize relay R-XX02. The normally-open contacts of relay R-XX02 connect the output signal of high-signal selector TY-XX01 to current-to-pneumatic transducer IP-XX01. The pneumatic output of transducer IP-XX01 places the dampers at the minimum position set on minimum position switch MPS-XX01 or under control of space-temperature controller TC-XX01, whichever signal is higher.

(4) Temperature controller TC-XX01, with its temperature transmitter in the space served, through current-to-pneumatic transducer IP-XX02, modulates heating-coil valve VLV-XX01, and during the occupied mode alter the expiration of the ventilation-delay mode, modulates the control dampers in sequence with the heating-coil valve to maintain the temperature controller setpoint.

(5) On a fall in temperature to its setpoint, low-temperature-protection thermostat TSL-XX01 opens a set of closed contacts in the supply-fan circuit, deenergizing the supply fan. Through its open contacts, thermostat TSL-

XX01 energizes relay R-XX05 and lights pilot light PL-XX04. The contacts of relay R-XX05 energize relay R-XX07. The normally-closed contacts of relay R-XX07 de-energize the supply fan, the normally-open contacts lock in relay R-XX07. To restart the fan after a low-temperature shutdown, both the low-temperature-protection thermostat TSL-XX01 and the control panel must be reset. The control panel is reset by depressing manual switch HS-XX02.

(6) Whenever smoke detector SMK-XX01 or smoke detector SMK-XX02 detects the presence of smoke, its normally-closed contacts in the supply-fan start circuit open, de-energizing the fan. The normally-open contacts close, energizing relay R-XX06 and lighting pilot light PL-XX05. Normally-open contacts of relay R-XX06 close, energizing relay R-XX07. Normally-closed contacts of relay R-XX07 in the supply-fan start circuit open, and the normally-open contacts close to lock-in relay R-XX07. To restart the fan after a smoke shutdown, smoke detectors SMK-XX01 and/or SMK-XX02 and the control panel must be reset. The control panel is reset by depressing manual switch HS-XX02.

(7) Differential-pressure gauge DPI-XX01 across the filter provides local indication of filter loading. On a rise in pressure drop across the filter to its setpoint, differential-pressure switch DPS-XX01 turns on pilot light PL-XX03.

(8) At the conclusion of the occupied mode, the occupied contacts of time clock CLK-XX01 open, and relay R-XX01 is de-energized. The contacts of relay R-XX01 open, de-energizing the supply fan and placing it under the control of the night thermostat TSL-XX02.

4-18. Multizone HVAC control system with return fan

a. Description of the HVAC system. This is an air-handling system with supply and return fans, economizer dampers, a cold deck with a cooling coil, a hot deck with a heating coil, individual-zone mixing dampers, and individual-zone heating controls. Figures 4-14A through 4-14F show the design for this type of air-handling system.

b. General sequence of operation.

(1) *Supply and return fans off.* When the fans are off, the cooling-coil valve and the outside-air and relief-air dampers are closed. The return-air damper is open. The heating-coil valve is modulated under the control of the hot-deck temperature controller. Zone dampers are under the control of their zone thermostats.

(2) *Supply and return fans operating.* When the fans are on, the control dampers are either positioned for full recirculation of air, positioned to introduce minimum outside air, or modulated to maintain mixed-air temperature. The cooling-coil valve is either closed or modulated to maintain the cold-deck-discharge temperature. The heating-coil valve is modulated to maintain the hot-deck discharge temperature. Zone dampers are under the control of their zone thermostats.

(3) *Control of supply fan and return fan.* Unless the fans are stopped as the result of a safety shutdown, they

are on or off as required by the control system's mode of operation.

(4) *Safety shutdown of the fans.* The control system shuts down the fans if there is a low-temperature condition or if smoke is detected.

(5) *Low-temperature detection.* On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply and return fans. To restart the fans, the thermostat and the control panel must be manually reset.

(6) *Smoke detection.* Duct smoke detectors stop the supply and return fans whenever either detects the presence of smoke. To restart the fans, the smoke detectors and control panel must be manually reset.

(7) *Filter condition.* Filter condition is monitored by a pressure gauge and a differential-pressure switch. On a rise in pressure drop across the filter to the switch setpoint, the switch turns on a pilot light.

(8) *Economizer control.* When the control-system mode of operation no longer requires the outside-air, return-air, and relief-air dampers to be in their full-recirculation operating positions, the dampers are positioned to admit outside air for ventilation. The dampers then remain at minimum position until the economizer controller closes both its PV and DEV contacts. The economizer controller closes its PV contacts when the return-air temperature indicates that the building requires cooling rather than heating. The economizer controller closes its DEV contacts when the outside-air temperature is sufficiently below the return-air temperature to be effective for cooling. When both these contacts close, the dampers are modulated by mixed-air temperature control.

(9) *Mixed-air-temperature control.* A mixed-air temperature controller with its temperature transmitter in the mixed air modulates the outside-air and relief-air dampers between minimum position and fully open to maintain a mixed-air temperature of 55 degrees F. As the outside-air and relief-air dampers open, the return-air damper closes.

(10) *Cold-deck temperature control.* A cold-deck temperature controller with its temperature transmitter in the cold-deck discharge modulates the cooling-coil valve to maintain its setpoint temperature during the ventilation-delay and occupied modes.

(11) *Hot-deck temperature control.* A hot-deck temperature controller with its temperature transmitter in the heating-coil discharge modulates the heating-oil valve to maintain its temperature setpoint. Outside-air temperature controller TC-XX04 with its temperature transmitter in the outside-air lowers the setpoint of the hot-deck controller as outside-air temperature rises. On a fall in outside-air temperature, the reverse occurs.

(12) *Zone space-temperature control.* On a rising space temperature, each zone space thermostat modulates the zone mixing damper toward closed to the hot deck and open to the cold deck.

(13) *Unoccupied mode of operation.* Throughout the unoccupied mode, the outside-air and relief-air dampers and the cooling-coil valve remain closed, and the return-air damper remains open. The supply and return fans are

cycled by the system's night thermostat to maintain its low-limit space-temperature setpoint.

(14) Ventilation-delay mode of operation. During the ventilation-delay mode, the dampers remain as they were throughout the unoccupied mode, and the supply and return fans run continuously. Until the ventilation-delay mode ends, the HVAC system circulates return air to bring the building to comfort conditions, using a minimum of energy.

(15) Occupied mode of operation. The supply and return fans run continuously, and the outside-air and relief-air dampers are at minimum position or are under mixed-air-temperature control as previously described.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode under which the system operates. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay R-XX04 and lighting pilot light PL-XX02. The normally-closed contacts of relay R-XX04 open, preventing relay R-XX03 from being energized. The normally-open contacts of relay R-XX03 prevent any signal reaching current-to-pneumatic transducer IP-XX01. Thus, the dampers remain in their normal positions, with outside-air and relief-air dampers closed and return-air damper open.

(2) When the time-clock's occupied contacts close, relays R-XX01 and R-XX02 are energized, and pilot light PL-XX01 is turned on. The contacts of relay R-XX02 energize the supply fan. The auxiliary contacts of the supply-fan starter energize relay R-XX05 and, with the contacts of relay R-XX01, energize relay R-XX06. The contacts of relay R-XX06 place the cold-deck temperature controller in control of cooling-oil valve VLV-XX01. The outside-air and relief-air dampers remain closed and the return-air damper remains open.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode of operation, relay R-XX04 is de-energized. The normally-closed contacts of relay R-XX04, in series with the now closed but normally-open contacts of relays R-XX01 and R-XX05, energize relay R-XX03. The normally-open contacts of relay R-XX03 connect the output signal of high-signal selector TY-XX01 to current-to-pneumatic transducer IP-XX01. The pneumatic output of transducer IP-XX01 places the dampers at the minimum position set on minimum-position switch MPS-XX01, unless relay R-XX07 is energized. Economizer EC-XX01 controls the action of relay R-XX07. The economizer receives signals from outside-air temperature transmitter TT-XX02 and from return-air transmitter TT-XX03. The difference between the return-air temperature and the outside-air temperature controls the DEV contacts, and the return-air temperature controls the PV contacts. When both these contacts are closed, relay R-XX07 is energized and pilot light PL-XX03 is turned on. When relay R-XX07 is energized, its contacts connect the output of mixed-air controller TC-XX01 to high-signal selector TY-XX01 to modulate the outside-air and relief-air dampers between minimum position and fully open while modulating the

return-air damper in the opposite direction to maintain the mixed-air temperature controller setpoint.

(4) On a fall in temperature to its setpoint, low-temperature-protection thermostat TSL-XX01 open a set of closed contacts in the supply-fan starter circuit, de-energizing the supply fan. The auxiliary contacts of the supply-fan starter de-energize relay R-XX05, and the contacts of relay R-XX05 in the return-fan starter circuit de-energize the return fan. A set of open contacts in low-temperature-protection thermostat TSL-XX01 close, energizing relay R-XX08 and lighting pilot light PL-XX05. The contacts of relay R-XX08 energize relays R-XX10 and R-XX11. One set of the contacts of relay R-XX10 locks in relays R-XX10 and R-XX11, and another set de-energizes the supply fan. Relay R-XX11 de-energizes the return fan. To restart the fans after a low-temperature shutdown, both the low-temperature thermostat TSL-XX01, and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch H S-XX02.

(5) When smoke detector SMK-XX01 or smoke detector SMK-XX02 detects the presence of smoke, its normally-closed contacts in the supply-fan starter circuit open, de-energizing the supply-fan. The auxiliary contacts of the supply-fan starter de-energize relay R-XX05, and the contacts of relay R-XX05 in the return-fan starter circuit de-energize the return fan. Its normally-open contacts close, energizing relay R-XX09. The normally-open contacts of R-XX09 close, energizing relays R-XX10 and R-XX11. One set of contacts of relay R-XX10 (line 17) locks in relays R-XX10 and R-XX11. The other set of contacts of relay R-XX10 (line 101) de-energizes the supply fan, and the contacts of relay R-XX11 de-energize the return fan. To restart the fans after a smoke alarm shutdown, smoke detectors SMK-XX01 and/or SMK-XX02 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX02.

(6) Differential-pressure gauge DPI-XX01 across the filter provides local indication of filter loading. On a rise in pressure drop across the filter to its setpoint, differential-pressure switch DPS-XX01 turns on pilot light PL-XX04.

(7) Temperature controller TC-XX02, with its temperature transmitter TT-XX04 in the cooling-coil discharge, through the contacts of relay R-XX06 and current-to-pneumatic transducer IP-XX02, modulates cooling-coil valve VLV-XX01 to maintain its temperature setpoint. Relay R-XX06 is energized during the ventilation-delay and occupied modes. During the unoccupied mode, R-XX06 is de-energized, cooling-coil valve control is interrupted, and the valve closes.

(8) Hot-deck temperature controller TC-XX03, with its temperature transmitter TT-XX05 in the heating coil discharge, modulates hot-deck heating coil valve VLV-XX02 to maintain its temperature setpoint. Controller TC-XX04 with temperature transmitter TT-XX02 in the outside air raises the setpoint of controller TC-XX03 on a fall in outside-air temperature and lowers it on a rise in outside-air temperature.

(9) On a rising zone space temperature, thermostat T-XXXX modulates damper actuator DA-XXXX to gradually close the zone damper to the hot deck and open it to the cold deck. The reverse occurs on a falling zone space temperature.

(10) When the occupied contacts of time clock CLK-XX01 open to end the occupied mode and index the system to the unoccupied mode, relays R-XX01 and R-XX02 are de-energized and pilot light PL-XX01 is turned off. The contacts of relay R-XX02 open, de-energizing the supply fan and placing the system's night thermostat TSL-XX02 in control of the supply fan, and, through interlock, in control of the return fan. On a fall in space temperature to degrees F, the contacts of TSL-XX02 close, energizing both fans; on a rise in temperature to 60 degrees F, the contacts open, de-energizing the fans.

4-19. Dual-duct HVAC control system with return fan

a. Description of the HVAC system. This is an air-handling system with supply and return fans, economizer dampers, a cold duct with a cooling coil, and a hot duct with a heating coil. In addition, each dual-duct zone has a thermostat and a dual-duct box with damper and damper actuator. Figures 4-15A through 4-15F show the design for this type of air-handling system.

b. General sequence of operation.

(1) *Supply and return fans off* When the fans are off, the cooling-coil valve and the outside-air and relief-air dampers are closed. The return-air damper is open. The heating-coil valve is modulated under the control of the hot-duct temperature controller. Dual-duct boxes are under the control of their zone thermostats.

(2) *Supply and return fans operating.* When the fans are on, the control dampers and the cooling-coil and heating-coil valves are operated as required by the system's mode of operation. The control dampers are either positioned for full recirculation of air, positioned to introduce minimum outside air, or modulated to maintain mixed-air temperature. The cooling-coil valve is either closed, or modulated to maintain the cold duct discharge temperature setpoint. The heating-coil valve is modulated to maintain the hot-duct discharge temperature. Dual-duct boxes are under the control of their thermostats.

(3) *Control of supply and return fans.* Unless the fans are stopped as the result of a safety shutdown, they are on or off as required by the control system's mode of operation.

(4) *Safety shutdown of the fans.* The control system shuts down the fans if there is a low-temperature condition, or if smoke is detected.

(5) *Low-temperature detection.* On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply and return fans. To restart the fans, the thermostat and the control panel must be manually reset.

(6) *Smoke detection.* Duct smoke detectors stop the supply and return fans whenever either detects the presence of smoke. To restart the fans, the smoke detectors and control panel must be manually reset.

(7) *Filter condition.* Filter condition is monitored by a pressure gauge and a differential-pressure switch. When the pressure drop across the filter reaches the switch setpoint, the switch turns on a pilot light.

(8) *Economizer control.* When the control system's mode of operation no longer requires the outside-air, return-air, and relief-air dampers to be in their full-recirculating positions, the dampers are positioned to admit outside air for ventilation. The dampers then remain at minimum position until the economizer controller closes both its PV and DEV contacts. The economizer controller closes its PV contacts when the return-air temperature indicates that the building requires cooling rather than heating. The economizer controller closes its DEV contacts when the outside-air temperature is sufficiently below the return-air temperature to be effective for cooling. When both these contacts close, the dampers are modulated by mixed-air temperature control.

(9) *Mixed-air temperature control.* A mixed-air temperature controller with its temperature transmitter in the mixed air modulates the outside-air damper and relief-air dampers between minimum position and fully open to maintain a mixed-air temperature of 55 degrees F. As the outside-air and relief-air dampers open, the return-air damper closes.

(10) *Cold-duct temperature control.* A cold-duct temperature controller with its temperature transmitter in the cold-duct discharge modulates the cooling-coil valve to maintain its setpoint temperature, during the ventilation-delay and occupied modes.

(11) *Hot-duct temperature control.* A hot-duct temperature controller with its temperature transmitter in the heating-coil discharge modulates the heating-coil valve to maintain its temperature setpoint. Another controller with a temperature transmitter in the outside air lowers the setpoint of the hot-duct controller as outside-air temperature rises. On a fall in outside-air temperature the reverse occurs.

(12) *Zone space-temperature control.* On a rise in temperature, each zone thermostat modulates the zone dual-duct-box damper actuator to maintain its setpoint.

(18) *Unoccupied mode of operation.* Throughout the unoccupied mode, the outside-air and relief-air dampers and the cooling coil valve remain closed, and the return-air damper remains open. The supply and return fans are cycled by the system's night thermostat to maintain its low-limit space-temperature setpoint.

(14) Ventilation-delay mode of operation. During the ventilation-delay mode, the dampers remain as they were throughout the unoccupied mode, and the supply and return fans run continuously. Until the ventilation-delay mode ends, the HVAC system circulates return air to bring the building to comfort conditions, using a minimum of energy.

(15) Occupied mode of operation. The supply and return fans run continuously, and the outside-air and relief-air dampers are at minimum position or are under mixed-air temperature control as previously described.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode of system operation. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay R-XX04 and lighting pilot light PL-XX02. The normally-closed contacts of relay R-XX04 open, preventing relay R-XX03 from being energized. The normally-open contacts of relay R-XX03 prevent any signal reaching current-to-pneumatic transducer IP-XX01. Thus, the dampers remain in their normal positions, with outdoor-air and relief-air dampers closed and return-air damper open.

(2) When the time-clock's occupied contacts close, relays R-XX01 and R-XX02 are energized and pilot light PL-XX01 is turned on. The contacts of relay R-XX02 energize the supply fan. The auxiliary contacts of the supply-fan starter energize relay R-XX05, energizing the return fan, and, with the contacts of relay R-XX01, energize relay R-XX06. The contacts of relay R-XX06 put the cold-duct temperature controller in control of cooling-coil valve VLV-XX01. The outside-air and relief-air dampers remain closed and the return-air damper remains open.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode of operation, relay R-XX04 is de-energized and pilot light PL-XX02 is turned off. The normally-closed contacts of relay R-XX04, in series with the now closed but normally-open contacts of relays R-XX03 connect the output signal of high-signal selector TY-XX01 to current-to-pneumatic transducer IP-XX01. The pneumatic output of transducer IP-XX01 places the dampers at the minimum position set on minimum-position switch MPS-XX01, unless relay R-XX07 is energized. Economizer EC-XX01 controls the action of relay R-XX07. The economizer receives signals from outside-air temperature transmitter TT-XX02 and from return-air transmitter TT-XX03. The difference between the return-air temperature and the outside-air temperature controls the DEV contacts, and the return-air temperature controls the PV contacts. When both these contacts are closed, relay H-XX07 is energized and pilot light PL-XX03 is turned on. When relay R-XX07 is energized, its contacts connect the output of mixed-air controller TC-XX01 to high-signal selector TY-XX01 to modulate the outside-air and return-air dampers between minimum position and fully open, while modulating the return-air damper in the opposite direction to maintain the mixed-air temperature controller setpoint.

(4) On a fall in temperature to its setpoint, low-temperature-protection thermostat TSL-XX01 opens a set of closed contacts in the supply-fan circuit, deenergizing the supply fan. The auxiliary contacts of the supply fan starter deenergize relay R-XX05, and the contacts of relay R-XX05 in the return-fan starter circuit de-energize the return fan. A set of open contacts in low-temperature-protection thermostat TSL-XX01 close, energizing relay R-XX08 and lighting pilot light PL-XX05. The contacts of relay R-XX08 energize relays H-XX10 and R-XX11. One set of the contacts of relay R-XX10 locks in relays R-

XX10 and R-XX11, and another set de-energizes the supply fan. The contacts of relay H-XX11 de-energize the return fan. To restart the fans after a low-temperature shutdown, both the low-temperature thermostat TSL-XX01 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX02.

(5) When smoke detector SMK-XX01 or smoke detector SMK-XX02 detects the presence of smoke, its normally-closed contacts in the supply-fan starter circuit open, de-energizing the supply fan. The auxiliary contacts of the supply-fan starter de-energize relay R-XX05, and the contacts of relay R-XX05 in the return-fan starter circuit de-energize the return fan. Its normally-open contacts close, energizing relay R-XX09. The normally-open contacts of R-XX09 close, energizing relays R-XX10 and R-XX11. One set of contacts of relay R-XX10 locks in relays R-XX10 and R-XX11. The other set of the contacts of relay R-XX10 de-energizes the supply fan, and the contacts of relay R-XX11 de-energize the return fan. To restart the fans after a smoke alarm shutdown, smoke detectors SMK-XX01 and/or SMK-XX02 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX02.

(6) Differential-pressure gauge DPI-XX01 across the filter gives local indication of filter loading. On a rise in pressure drop across the filter to its setpoint, differential-pressure switch DPS-XX01 turns on filter pilot light PL-XX04.

(7) Temperature transmitter TT-XX04 signals the cold-duct discharge temperature to temperature controller TC-XX02. During the ventilation-delay and occupied modes, relay R-XX06 is energized and its contacts close, allowing the TC-XX02 signal to be received by current-to-pneumatic transducer IP-XX02. The pneumatic output of IP-XX02 modulates cooling-coil valve VLV-XX01 to maintain the setpoint of controller TC-XX02. During the unoccupied mode, the contacts of relay R-XX06 are open, cooling-coil valve control is interrupted, and the valve closes.

(8) Hot-duct temperature controller TC-XX03, with its temperature transmitter TT-XX05 in the heating-coil discharge, modulates hot-duct heating coil valve VLV-XX02 to maintain its temperature setpoint. Controller TC-XX04, with its temperature transmitter TT-XX02 in the outside air, raises the setpoint of controller TC-XX03 on a fall in outside-air temperature, and lowers it on a rise in outside-air temperature.

(9) On a rising space temperature, thermostat T-XXXX modulates dual-duct box actuator DA-XXXX to gradually close the box to the hot duct and gradually open it to the cold duct.

(10) When the occupied contacts of time clock CLK-XX01 open to end the occupied mode and index the system to the unoccupied mode, relays R-XX01 and R-XX02 are de-energized and pilot light PL-XX01 is turned off. The contacts of relay R-XX02 open, de-energizing the supply fan and placing the system's night thermostat TSL-XX02 in control of the supply fan, and, through interlock as

previously described, in control of the return fan. On a fall in space temperature to 55 degrees F, the contacts of TSL-XX02 close, energizing both fans; on a rise in temperature to 60 degrees F, the contacts open, deenergizing the fans.

4-20. Bypass multizone HVAC control system with return fan

a. Description of the HVAC system. This is an air-handling system with supply and return fans, economizer dampers, a cold deck with a cooling coil, a bypass deck, individual-zone mixing dampers, and individual-zone heating controls. Figures 4-16A through 4-16F show the design for this type of air-handling system.

b. General sequence of operation.

(1) Supply-air and return-air fans off. When the fans are off, the cooling-coil valve, the outside-air and relief-air dampers are closed. The return-air damper is open. Zone heating-coil valves and dampers are under the control of their zone thermostats.

(2) Supply-air and return-air fans operating. When the fans are on, the control dampers and the cooling-coil valve are operated as required by the system's mode of operation. Zone heating-coil valves and dampers are under the control of their zone thermostats. The control dampers are either positioned for full recirculation of air, positioned to introduce minimum outside air, or modulated to maintain mixed-air temperature. The cooling-coil valve is either closed, or modulated to maintain cold-deck temperature.

(3) Control of supply-air and return-air fans. Unless the fans are stopped as the result of a safety shutdown, they are on or off as required by the control system's mode of operation.

(4) Safety shutdown of the fans. The control system shuts down the fans if there is a low-temperature condition, or if smoke is detected.

(5) Low-temperature detection. On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply-air and return-air fans. To restart the fans, the thermostat and the control panel must be manually reset.

(6) Smoke detection. Duct smoke detectors stop the supply-air and return-air fans whenever either detects the presence of smoke. To restart the fans, the smoke detectors and control panel must be manually reset.

(7) Filter condition. Filter condition is monitored by a pressure gauge and a differential-pressure switch. On a rise in pressure-drop across the filter to the switch setpoint, the switch turns on a pilot light.

(8) Economizer control. When the control system modes of operation no longer require the outside-air, return-air, and relief-air dampers to be in their full-recirculation positions, the dampers are positioned to admit outside air for ventilation. The dampers then remain at minimum position until the economizer controller closes both its PV and DEV contacts. The economizer controller closes its PV contacts when the return-air temperature indicates that the building requires cooling rather than heating. The economizer controller closes its DEV contacts when the outside-air temperature is sufficiently below the

return-air temperature to be effective for cooling. When both these contacts close, the dampers are modulated by mixed-air temperature control.

(9) Mixed-air temperature control. A mixed-air temperature controller with its temperature transmitter in the mixed air modulates the outside-air and relief-air dampers between minimum position and fully open, to maintain a mixed-air temperature of 55 degrees F. As the outside-air and relief-air dampers open, the return-air damper closes.

(10) Cold-deck temperature control. A cold-deck temperature controller with its temperature transmitter in the cold-deck discharge modulates the cooling-coil valve to maintain its setpoint temperature. During the unoccupied mode, the cooling-coil valve is not controlled and remains closed.

(11) Space-temperature control. On a rise in temperature, each zone thermostat first modulates its zone-reheat-coil valve toward closed. On a further rise in temperature after a space-temperature deadband, each zone thermostat modulates its cold-deck damper toward open and simultaneously modulates its bypass damper toward closed.

(12) Unoccupied mode of operation. Throughout the unoccupied mode, the outside-air and relief-air dampers and the cooling-coil valve remain closed, and the return-air damper remains open. The supply and return fans are cycled by the system's night thermostat to maintain its low-limit space-temperature setpoint.

(13) Ventilation-delay mode of operation. During the ventilation-delay mode, the dampers remain as they were throughout the unoccupied mode, and the supply-air and return-air fans run continuously. Until the ventilation-delay mode ends, return air is circulated, to bring the building to comfort conditions using a minimum of energy.

(14) Occupied mode of operation. The supply-air and return-air fans run continuously, and the outside-air and relief-air dampers are at minimum position or are under mixed-air temperature control as previously described.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode under which the system operates. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay R-XX04 and lighting pilot light PL-XX02. The normally-closed contacts of relay R-XX04 open, preventing relay R-XX03 from being energized. The normally-open contacts of relay R-XX03 prevent any signal reaching current-to-pneumatic transducer IP-XX01. Thus, the dampers remain in their normal positions with outside-air and relief-air dampers closed and return-air damper open.

(2) When the time clock's occupied contacts close, relays R-XX01 and R-XX02 are energized and pilot light PL-XX01 is turned on. The contacts of relay R-XX02 energize the supply fan. The auxiliary contacts of the supply fan energize relay R-XX05 and, with contacts of relay R-XX01, energize relay R-XX06. The contacts of relay R-XX06 places the cold-deck temperature controller in control of cooling-coil valve VLV-XX01. The outside-air

and relief-air dampers remain closed and the return-air damper remains open.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode of operation, relay R-XX04 is de-energized and pilot light PL-XX02 is turned off. The normally-closed contacts of relay H-XX04, in series with the now closed but normally-open contacts of relays H-XX01 and R-XX05, energize relay H-XX03. The normally-open contacts of relay R-XX03 connect the output signal of high-signal selector TY-XX01 to current-to-pneumatic transducer IP-XX01. The pneumatic output of transducer IP-XX01 places the dampers at the minimum position set on minimum-position switch MPS-XX01, unless relay H-XX07 energized. Economizer EC-XX01 controls the action of relay H-XX07. The economizer receives signals from outside-air temperature transmitter TT-XX02 and from return-air temperature transmitter TT-XX03. The difference between the return-air temperature and the outside-air temperature controls the DEV contacts, and the return-air temperature controls the PV contacts. When both these contacts are closed, relay H-XX07 is energized and pilot light PL-XX03 is turned on. When relay R-XX07 is energized, its contacts connect the output of mixed-air controller TC-XX01 to high-signal selector TY-XX01 to modulate the outside-air and return-air dampers between minimum position and fully open while modulating the return-air damper in the opposite direction to maintain the temperature controller setpoint.

(4) On a fall in temperature to its setpoint, low-temperature-protection thermostat TSL-XX01 opens a set of closed contacts in the supply-fan circuit, deenergizing the supply fan. The auxiliary contacts of the supply-fan starter de-energize relay H-XX05, and the contacts of relay R-XX05 in the return-fan starter circuit de-energize the return fan. A set of open contacts in low-temperature-protection thermostat TSL-XX01 close, energizing relay H-XX08 and lighting pilot light PL-XX05. The contacts of relay H-XX08 energize relays H-XX10 and R-XX11. One set of the contacts of relay R-XX10 locks in relays H-XX10 locks in relays H-XX10 and H-XX11, and another set de-energizes the supply fan. The contacts of relay R-XX11 de-energize the return fan. To restart the fans after a low-temperature shutdown, both the low-temperature thermostat TSL-XX01 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX02.

(5) When smoke detector SMK-XX01 or smoke detector SMK-XX02 detects the presence of smoke, its normally-closed contacts in the supply-fan starter circuit open, de-energizing the supply fan. The auxiliary contacts of the supply-fan starter dc-energize relay R-XX05, and the contacts of relay H-XX05 in the return-fan starter circuit dc-energize the return fan. Its normally-open contacts close, energizing relay R-XX09. The normally-open contacts of R-XX09 close, energizing relays H-XX10 and R-XX11. One set of the contacts of relay H-XX10 locks in relays R-XX10 and H-XX11; the other set de-energize the supply fan. The contacts of relay R-XX11 de-energize

the return fan. To restart the fans after a smoke-alarm shutdown, smoke detectors SMK-XX01 and/or SMK-XX02 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX02.

(6) A differential-pressure gauge DPI-XX01 across the filter gives local indication of filter loading. On a rise in pressure drop across the filter to its setpoint, differential-pressure switch DPS-XX01 turns on pilot light PL-XX04.

(7) Temperature transmitter TT-XX04 signals the cold-deck discharge temperature to temperature controller TC-XX02. During the ventilation-delay and occupied modes, relay R-XX06 is energized and its contacts close, allowing the TC-XX02 signal to be received by current-to-pneumatic transducer IP-XX02. The pneumatic output of IP-XX02 modulates cooling-coil valve VLV-XX01 to maintain the setpoint of controller TC-XX02. During the unoccupied mode, H-XX06 is deenergized, cooling-coil valve control is interrupted, and the valve closes.

(8) On a rising space temperature, thermostat T-XXXX first modulates reheat coil valve VLV-XXXX closed, through the auxiliary actuator driver (AAD) of damper actuator DA-XXXX, and on a further temperature rise modulates DA-XXXX to close the zone damper to the bypass duct and open it to the cold duct.

(9) When the occupied contacts of time clock CLK-XX01 open to end the occupied mode and index the system to the unoccupied mode, relays R-XX01 and H-XX02 are dc-energized, and pilot light PL-XX01 is turned off. The contacts of relay H-XX02 open, dc-energizing the supply fan and placing the system's night thermostat TSL-XX02 in control of the supply fan and, through interlock, in control of the return fan. On a fall in space temperature toss degrees F, the contacts of TSL-XX02 close, energizing both fans; on a rise in temperature to 60 degrees F, the contacts open, dc-energizing the fans.

4-21. Variable-air-volume HVAC control system without return fan

a. Description of the HVAC system. This is an air-handling system with an inlet-vane-equipped supply fan, economizer dampers, filters, and cooling coil. Variable-air-volume boxes, some of which are equipped with heating coils, are located downstream in ductwork near the areas served by the system. Figures 4-17A through 4-17F show the design for this type of air-handling system.

B. General sequence of operation.

(1) Supply fan off. When the fan is off, the cooling-coil valve and the outside-air, relief-air, and supply-fan inlet vane dampers are closed. The return-air damper is open.

(2) Supply fan operating. When the supply fan is on, the cooling-coil valve and the control dampers are operated as required by the system's mode of operation. The control dampers are either positioned for full recirculation of air, positioned to introduce minimum outside air, or modulated to maintain the mixed-air temperature. The cooling-coil valve is either closed, or modulated to maintain unit-

discharge temperature.

(3) Control of supply fan. Unless the fan is stopped as the result of a safety shutdown, it is on or off as required by the control system's mode of operation.

(4) Safety shutdown of the fan. The control system shuts down the fan if there is a low-temperature condition, if smoke is detected, or if a high static-pressure condition is detected.

(5) Low-temperature detection. On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply fan. To restart the fan, the thermostat and the control panel must be manually reset.

(6) Smoke detection. Duct smoke detectors stop the supply fan whenever either detects the presence of smoke. To restart the fan, the smoke detectors and the control panel must be manually reset.

(7) High-static-pressure detection. On a rise in static pressure above the setpoint of a high-limit static-pressure switch downstream of the fan, the fan stops. To restart the fan, the control panel must be manually reset.

(8) Filter condition. Filter condition is monitored by a pressure gauge and a differential-pressure switch. When the pressure drop across the filter reaches the switch setpoint, the switch turns on a pilot light.

(9) Economizer control. When the control system's mode of operation no longer requires the outside-air, return-air, and relief-air dampers to be in their full-recirculating positions, the dampers are positioned to admit outside air for ventilation. The dampers then remain at minimum position until the economizer controller closes both its PV and DEV contacts. The economizer controller closes its PV contacts when the return-air temperature indicates that the building requires cooling rather than heating. The economizer controller closes its DEV contacts when the outside-air temperature is sufficiently below the return-air temperature to be effective for cooling. When both these contacts close, the dampers are modulated by mixed-air-temperature control.

(10) Mixed-air temperature control. A mixed-air temperature controller with its temperature transmitter in the mixed air modulates the outside-air damper and relief-air dampers between minimum position and fully open, to maintain a mixed-air temperature of 55 degrees F. As the outside-air and relief-air dampers open, the return-air damper closes.

(11) Cooling-coil temperature control. A cooling-coil temperature controller with its temperature transmitter in the unit discharge modulates the cooling-coil valve during the ventilation-delay and occupied modes to maintain its setpoint temperature. During the unoccupied mode, the cooling-coil valve is not controlled and remains closed.

(12) Space-temperature control. Each controlled space is equipped with a Variable-air-volume (VAV) box, which is controlled by a microprocessor-based VAV-box controller. The controller receives temperature signals from a temperature-sensing element in the space served and from a flow sensor upstream of the VAV box. On a fall in space temperature, the controller modulates the dampers toward minimum position, to maintain the

cooling-mode setpoint. After the minimum position is reached, the controller is inactive while the space temperature falls through a temperature deadband. On a further fall in temperature below the temperature deadband, the heating-coil valve modulates to maintain the heating-mode setpoint.

(13) Unoccupied mode of operation. Throughout the unoccupied mode, the outside-air and relief-air dampers and the cooling-coil valve remain closed, and the return-air damper remains open. The supply fan is cycled by the system's night thermostat to maintain its low-light space-temperature setpoint.

(14) Ventilation-delay mode of operation. During the ventilation-delay mode, the dampers remain as they were throughout the unoccupied mode, and the supply fan runs continuously. Until the ventilation-delay mode ends, return air is circulated, to bring the building to comfort conditions using a minimum of energy.

(15) Occupied mode of operation. The supply fan runs continuously, and the outside-air and relief-air dampers are at minimum position or are under mixed-air temperature control as previously described.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode of system operation. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay H-XX04 and lighting pilot light PL-XX02. The normally-closed contacts of relay H-XX04 open, preventing relay R-XX03 from being energized. The normally-open contacts of relay H-XX03 prevent any signal from reaching current-to-pneumatic transducer IP-XX01. Thus, the dampers remain in their normal positions, with outside-air and relief-air dampers closed and return-air damper open.

(2) When the time clock's occupied contacts close, relays H-XX01 and H-XX02 are energized and pilot light PL-XX01 is turned on. The contacts of relay H-XX02 energize the supply fan. The auxiliary contacts of the supply-fan starter energize relay H-XX05 and relay H-XX07, and, with the contacts of relay H-XX01, energize relay H-XX06. The contacts of relay H-XX06 enable discharge temperature controller TC-XX02 to control cooling-coil valve VLV-XX01. The outside-air and relief-air dampers remain closed and the return-air damper remains open.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode of operation, relay R-XX04 is de-energized and pilot light PL-XX01 is turned off. The normally-closed contacts of relay H-XX04, in series with the now closed but normally-open contacts of relays H-XX01 and H-XX05, energize relay H-XX03. The normally-open contacts of relay H-XX03 connect the output signal of high-signal selector TY-XX01 to current-to-pneumatic transducer IP-XX01. The pneumatic output of transducer IP-XX01 places the dampers at the position set on minimum-position switch MPX-XX01, unless relay H-XX08 is energized. Economizer EC-XX01 controls the action of relay R-

XX08. The economizer receives signals from outside-air temperature transmitter TT-XX02 and from return-air transmitter TT-XX03. The difference between the return-air temperature and the outside-air temperature controls the DEV contacts, and the return-air temperature controls the PV contacts. When both these contacts are closed, relay R-XX08 is energized and pilot light PL-XX03 is turned on. When relay R-XX08 is energized, its contacts connect the output of mixed-air controller TC-XX01 to high-signal selector TY-XX01, to modulate the outside-air and return-air dampers between minimum position and fully open while modulating the return-air damper in the opposite direction to maintain the temperature controller setpoint.

(4) On a fall in temperature to its setpoint, low-temperature-protection thermostat TSL-XX01 opens a set of closed contacts in the supply-fan circuit, deenergizing the supply fan. A set of open contacts in low-temperature-protection thermostat TSL-XX01 closes, energizing relay R-XX09 and lighting pilot light PL-XX05. The contacts of relay R-XX09 energize relay R-XX12. One set of the contacts of relay R-XX12 locks in relay R-XX12, and another set de-energizes the supply fan. To restart the fans after a low-temperature shutdown, both low-temperature thermostat TSL-XX01 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX03.

(5) When smoke detector SMK-XX01 or smoke detector SMK-XX02 detects the presence of smoke, its normally-closed contacts in the supply-fan starter circuit open, de-energizing the supply fan. Its normally-open contacts of R-XX10 close, energizing relay R-XX12. One set of contacts of relay R-XX12 locks in relay R-XX12. The other set of contacts of relay R-XX12 de-energizes the supply fan. To restart the fans after a smoke-alarm shutdown, smoke detectors SMK-XX01 and/or SMK-XX02 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX03.

(6) Differential-pressure gauge DPI-XX01 across the filter gives local indication of filter loading. On a rise in pressure drop across the filter to its setpoint, differential-pressure switch DPS-XX01 turns on filter pilot light PL-XX04.

(7) Temperature controller TC-XX02, with its temperature transmitter TT-XX04 in the unit discharge, through the contacts of relay R-XX06 and current-to-pneumatic transducer IP-XX02 modulates cooling-coil valve VLV-XX01 to maintain its temperature setpoint. The contacts of relay R-XX06 are closed during the ventilation-delay and occupied modes, allowing control. The contacts are open during the unoccupied mode, the cooling-coil valve control is interrupted, and the valve closes.

(8) A pressure-sensing element and transmitter DPT-XX01 located in the supply duct (the location is determined by field conditions) signals duct static pressure to controller PC-XX01. Whenever the supply fan runs, the

auxiliary contacts of the fan starter energize relay R-XX07. The output of pressure controller PC-XX01 is sent, through the contacts of relay R-XX07, to current-to-pneumatic transducer IP-XX03. The pneumatic output of the transducer modulates the supply-fan inlet-vane actuator DA-XX04 to maintain the pressure-controller setpoint. When the fan is de-energized, relay R-XX07 is de-energized, its contacts open, and the inlet-vane dampers close.

(9) When the setpoint of high-limit static-pressure switch DPS-XX02 in the supply-fan discharge is exceeded, its contacts close, energizing relay R-XX11 and lighting static pilot light PL-XX07. One set of the contacts of relay R-XX11 locks in relay R-XX11, and another set of contacts energizes relay R-XX12. One contacts deenergizes the supply fan. To restart the fan, manual switch HS-XX02 must be momentarily depressed and then manual switch HS-XX03 must be depressed.

(10) Temperature-sensing element TE-XXXX and duct air-flow sensing element FE-XXXX signal the VAV box controller to modulate reheat-coil valve VLV-XXXX and VAV box damper actuator DA-XXXX. Valve VLV-XX01 opens after the VAV box is at its minimum flow position. There is a space temperature dead band between the minimum flow position and the opening of the valve. On a rising space temperature, the VAV box controller first gradually closes VLV-XXXX and then gradually opens the VAV box beyond minimum air-flow position to maximum air-flow position after the space temperature passes through the dead band.

(11) When the occupied contacts of time clock TC-XX01 open to end the occupied mode and index the system to the unoccupied mode, relays R-XX01 and R-XX02 are de-energized and pilot light PL-XX01 is turned off. The contacts of relay R-XX02 open, de-energizing the supply fan and placing the system's night thermostat TSL-XX02 in control of the supply fan. On a fall in space temperature to 55 degrees F, the contacts of TSL-XX02 close, energizing the supply fan; on a rise in temperature to 60 degrees F, the contacts open, de-energizing the fan.

4-22. Variable-air-volume HVAC control system with return fan

a. Description of the HVAC system. This is an air-handling system with inlet-vane-equipped supply and return fans, economizer dampers, filters, and cooling coil. Variable-air-volume (VAV) boxes, some of which have heating coils are located downstream in the ductwork near the areas served by the system. Figures 4-18A through 4-18F show the design for this type of air-handling system.

b. General sequence of operation.

(1) *Supply and return fans off* When the fans are off, the cooling-coil valve, outside-air, relief-air, supply-fan inlet-vane and return-air inlet-vane dampers are closed, and the return-air damper is open.

(2) *Supply and return fans operating.* When the fans are on, the cooling-coil valve and the control dampers are operated as required by the system's mode of operation. The control dampers are either positioned for full recir-

ulation of air, positioned to introduce minimum outside air, or modulated to maintain mixed-air temperature. The cooling-coil valve is either closed, or modulated to maintain unit discharge temperature.

(3) *Control of supply and return fans.* Unless the fans are stopped as the result of a safety shutdown, they are on or off as required by the control system's mode of operation. When the fans are on, the inlet vanes are modulated to maintain the required static pressure.

(4) *Safety shutdown of the fans.* The control system shuts down the fans if there is a low-temperature condition, if smoke is detected, or if a high-static-pressure condition is detected.

(5) *Low-temperature detection.* On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply and return fans. To restart the fans, the thermostat and the control panel must be manually reset.

(6) *Smoke detection.* Duct smoke detectors stop the supply and return fans whenever either detects the presence of smoke. To restart the fans, the smoke detectors and control panel must be manually reset.

(7) *High-static-pressure detection.* On a rise in static pressure above the setpoint of a high-limit static-pressure switch downstream of the fan, the fans stop. To restart the fan, the control panel must be manually reset.

(8) *Filter condition.* Filter condition is monitored by a pressure gauge and a differential-pressure switch. On a rise in pressure-drop across the filter to the switch setpoint, the switch turns on a pilot light.

(9) *Economizer control.* When the control system's modes of operation no longer required the outside-air, return-air, and relief-air dampers to be in their full-recirculation positions, the dampers are positioned to admit outside air for ventilation. The dampers then remain at minimum position until the economizer controller closes both its PV and DEV contacts. The economizer controller closes its PV contacts when the return-air temperature indicates that the building requires cooling rather than heating. The economizer controller closes its DEV contacts with the outside-air temperature is sufficiently below the return-air temperature to be effective for cooling. When both these contact close, the dampers are modulated by mixed-air temperature control.

(10) *Mixed-air temperature control.* A mixed-air temperature controller with its temperature transmitter in the mixed air modulates the outside-air damper and relief-air dampers between minimum position and fully open, to maintain a mixed-air temperature of 55 degrees F. As the outside-air and relief-air dampers open, the return-air damper closes.

(11) *Cooling-coil temperature control.* A cooling-coil temperature controller with its temperature transmitter in the unit discharge modulates the cooling-coil valve to maintain its setpoint temperature. During the unoccupied mode, the cooling-coil valve is not controlled and remains closed.

(12) *Space-temperature control.* Each controlled space is equipped with a Variable-air-volume (VAV) box, which is controlled by a microprocessor-based VAV-box

controller. The controller receives temperature signals from a temperature-sensing element in the space served and from a flow sensor upstream of the VAV box. On a fall in space temperature, the controller modulates the dampers toward minimum position, to maintain the cooling mode setpoint. After the minimum position is reached, the controller is inactive while the space temperature falls through a temperature deadband. On a further fall in temperature below the temperature deadband, the heating-coil valve modulates to maintain the heating setpoint.

(13) *Unoccupied mode of operation.* Throughout the unoccupied mode, the outside-air and relief-air dampers and the cooling-coil valve remain closed, and the return-air damper remains open. The supply-air and return-air fans are cycled in unison by the system's night thermostat to maintain its low-limit space-temperature setpoint.

(14) *Ventilation-delay mode of operation.* During the ventilation-delay mode, the dampers remain as they were throughout the unoccupied mode, and the supply-air and return-air fans run continuously. Until the ventilation-delay mode ends, all air is recirculated, to bring the building to comfort conditions, using a minimum of energy.

(15) *Occupied mode of operation.* The supply-air and return-air fans run continuously, and the outside-air and relief-air dampers are at minimum position or are under mixed-air-temperature control as previously described.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode of system operation. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay R-XX04 and lighting pilot light PL-XX02. The normally-closed contacts of relay R-XX04 open, preventing relay R-XX03 from being energized. The normally-open contacts of relay R-XX03 prevent any signal from reaching current-to-pneumatic transducer IP-XX01. Thus, the dampers remain in their normal positions, with outside-air And relief- air dampers closed and return-air damper open.

(2) When the time-clock's occupied contacts close, relays R-XX01 and R-XX02 are energized and pilot light PL-XX01 is turned on. The contacts of relay R-XX02 energize the supply fan. The auxiliary contacts of the supply-fan starter energize relay R-XX05, and relay R-XX07, and, with the contacts of relay R-XX01, energize relay R-XX06. One set of contacts of relay R-XX05 energizes the return fan. The other set of contacts (line 4) is involved in the energizing of relay R-XX03 when the ventilation delay mode of operation is over. The contacts of relay R-XX06 put discharge-temperature controller in control of cooling-coil valve VLV-XX01. The outside-air and relief-air dampers remain closed and the return-air damper remains open.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode of operation, relay R-XX04 is de-energized and pilot light PL-XX01 is turned off. The normally-closed contacts of relay R-XX04, in series with the now closed but normally-open contacts of relays R-XX01 and R-XX05, energize

relay R-XX03. The open contacts of relay R-XX03 connect the output signal of high-signal selector TY-XX01 to current-to-pneumatic transducer IP-XX01. The pneumatic output of transducer IP-XX01 places the dampers at the minimum position set on minimum-position switch MPS-XX01, unless relay R-XX08 is energized. Economizer EC-XX01 controls the action of relay R-XX08. The economizer receives signals from outside-air temperature transmitter TT-XX02 and from return-air transmitter TT-XX03. The difference between the return-air temperature and the outside-air temperature controls the DEV contacts, and the return-air temperature controls the PV contacts. When both these contacts are closed, relay R-XX08 is energized and pilot light PL-XX03 is turned on. When relay R-XX08 is energized, its contacts connect the output of mixed-air controller TC-XX01 to high-signal selector TY-XX01 to modulate the outside-air and return-air dampers between minimum position and fully open while modulating the return-air damper in the opposite direction to maintain the temperature controller setpoint.

(4) On a fall in temperature to its setpoint, low-temperature-protection thermostat TSL-XX01 opens a set of closed contacts in the supply-fan circuit, deenergizing the supply fan. The auxiliary contacts of the supply-fan starter de-energize relay R-XX05, and the contacts of relay R-XX05 in the return-fan starter circuit de-energize the return fan. A set of normally-open contacts in low-temperature-protection thermostat TSL-XX01 close, energizing relay R-XX- and lighting pilot light PL-XX05. The contacts of relay R-XX- energize relay R-XX12 and relay R-XX13. One set of the contacts of relay R-XX12 locks in relays R-XX12 and R-XX13, and the normally-closed contacts of R-XX12 de-energize the supply fan. The normally-closed contacts of R-XX13 in the return-fan starter circuit de-energize the return fan. To restart the fans after a low-temperature shutdown, both low-temperature thermostat TSL-XX01 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX03.

(5) When either smoke detector SMK-XX01 or smoke detector SMK-XX02 detects the presence of smoke, its normally-open contacts close, energizing relay R-XX10 and turning on pilot light PL-XX06. The contacts of R-XX10 close, energizing relays R-XX12 and R-XX13. One set of contacts of relay R-XX12 locks in relays R-XX12 and R-XX13. The other set of the contacts of R-XX12 de-energizes the supply fan, and the contacts of relay R-XX13 de-energize the return fan. To restart the fans after a smoke-alarm shutdown, smoke detectors SMK-XX01 and/or SMK-XX02 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS09XX03.

(6) Differential-pressure gauge DPI-XX01 across the filter provides local indication of filter loading. On a rise in pressure drop across the filter to its setpoint, differential-pressure switch DPS-XX01 turns on filter pilot light PL-XX04.

(7) Temperature controller TC-XX02, with its temperature transmitter TT-XX04 in the unit discharge,

through current-to-pneumatic transducer IP-XX02, modulates cooling-coil valve VLV-XX01 during the ventilation-delay and occupied modes to maintain its setpoint. During the unoccupied mode, the contacts of relay R-XX01 keep relay R-XX06 de-energized, the contacts of relay R-XX06 interrupt the TC-XX02 output signal to valve VLV-XX01, and the valve remains closed.

(8) Pressure-sensing element and transmitter DPT-XX01 located in the supply duct (the location is determined by field conditions) sends pressure signals to pressure controller PC-XX01. Whenever the supply fans runs, the pressure-controller output is sent, through the contacts of relay R-XX07, to current-to-pneumatic transducer IP-XX03. The pneumatic output of the transducer modulates supply-fan inlet-vane actuator DA-XX04 to maintain the pressure-controller setpoint. When the fan is de-energized, relay R-XX07 is de-energized and the inlet-vane dampers close.

(9) When the setpoint of high-limit static-pressure switch DPS-XX02 in the supply-fan discharge is exceeded, its contacts close, energizing relay R-XX11 and lighting static pilot light PL-XX07. One set of the contacts of relay R-XX11 locks in relay R-XX11, and another set of contacts energizes relays R-XX12 and R-XX13. One set of the contacts of relay R09XX12 locks in relays R-XX12 and R-XX13, and the other set of R-XX12 contacts de-energizes the supply fan. The contacts of relay R-XX13 de-energize the return fan. To restart the fans, manual switch HS-XX02 must be momentarily depressed and then manual switch HS-XX03 must be depressed.

(10) Air-flow measuring station AFMA-XX01 in the supply-air duct and flow transmitter FT-XX01, and airflow measuring station AFMA-XX02 in the return-air duct and flow transmitter FT-XX02 send flow signals to flow controller FC-XX01. The output of FC-XX01, through the contacts of relay R09XX07, is sent to current-to-pneumatic transducer IP-XX04. The pneumatic output of IP-XX04 modulates the return-fan inlet-vane dampers to maintain the constant differential-air volume between the supply and return fans set on controller FC-XX01. When the fans are de-energized, relay R-XX07 is de-energized, its contacts open, breaking the control loop, and the return-fan inlet vanes close.

(11) Temperature-sensing element TE-XXXX and duct air-flow sensing element FE-XXXX signal the VAV-box controller to modulate reheat-coil valve VLV-XXXX and VAV-box damper actuator DA-XXXX. On a rising space temperature, the VAV-box controller first gradually closes VLV-XXXX and then gradually opens the VAV box beyond minimum air-flow position to maximum air-flow position.

(12) When the occupied contacts of time clock TC-XX01 open to end the occupied mode and index the system to the unoccupied mode, relays R-XX01 and R-XX02 are de-energized and pilot light PL-XX01 is turned off. The contacts of relay R-XX02 open, deenergizing the supply fan and placing the system's night thermostat TSL-XX02 in control of the supply fan, and, through the supply fan auxiliary contacts and relay R-XX05, in control of the

return fan. On a fall in space temperature to 55 degrees F, the contacts of TSL-XX02 close, energizing both fans; on a rise in temperature to 60 degrees F, the contacts open, de-energizing the fans.

4-23. Single-zone HVAC control system without return fan

a. Description of the HVAC system. The air-handling system consists of a supply fan, economizer dampers, filter, heating coil, and cooling coil. Figures 4-19A and 4-19F illustrate the design for this type of air-handling system.

b. General sequence of operation.

(1) *Supply fan off* When the fan is off, the cooling-coil valve and the outside-air and relief-air dampers are closed, and the return-air damper is open. The heating-coil valve remains under space-temperature control.

(2) *Supply fan operating.* When the fan is on, the control dampers and the cooling-coil valve are operated as required by the system's operational modes. The control dampers are positioned for full recirculation of air, positioned to introduce minimum outside air, or modulated to maintain space temperature. The cooling-coil valve is either closed, or modulated to maintain space temperature.

(3) *Control of supply fan.* Unless the fan is stopped as the result of a safety shutdown, it is on or off as required by the control system mode of operation.

(4) *Safety shutdown of the fan.* The control system shuts down the fan if there is a low-temperature condition, or if smoke is detected.

(5) *Low-temperature detection.* On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply fan. To restart the fan, the thermostat and the control panel must be manually reset.

(6) *Smoke detection.* Duct-smoke detectors stop the supply fan whenever either detects the presence of smoke. To restart the fan, the smoke detectors and control panel must be manually reset.

(7) *Filter condition.* Filter condition is monitored by a pressure gauge and a differential-pressure switch. When the rise in pressure-drop across the filter reaches the switch setpoint, the switch turns on a pilot light.

(8) *Economizer control.* When the system does not need full return-air recirculation, the dampers are set at minimum position until the economizer controller closes both its PV and DEV contacts. The economizer controller closes its PV contacts when the return-air temperature indicates that the building requires cooling rather than heating. The economizer controller closes its DEV contacts when the outside-air temperature is sufficiently below the return-air temperature to be effective for cooling. When both these contacts close, the dampers are modulated as part of the space-temperature control.

(9) *Space-temperature control.* On a rise in space temperature, the heating-coil valve is modulated toward closed. On a further rise in temperature, the outside-air and relief-air dampers are modulated from minimum position toward fully open while the return-air damper is modulated toward fully closed. On a still further rise in space temperature, the cooling-coil valve is modulated toward

open. The reverse occurs on a fall in temperature.

(10) *Unoccupied mode of operation.* Throughout the unoccupied mode, the outside-air and relief-air dampers and the cooling-coil valve remain closed, and the return-air damper remains open. The supply fan is cycled by the system's night thermostat to maintain its low-limit space-temperature setpoint.

(11) *Ventilation-delay mode of operation.* During the ventilation-delay mode, the dampers remain as they were throughout the unoccupied mode, and the supply fan runs continuously. Until the ventilation-delay mode ends, return air is circulated, to bring the space to comfort conditions using a minimum of energy. Heating-coil and cooling-coil valves are under space-temperature control.

(12) *Occupied mode of operation.* The supply fan runs continuously, and the outside-air and relief-air dampers are at a minimum position or are under space-temperature control as previously described.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode of system operation. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay R-XX04 and lighting pilot light PL-XX02. The normally closed contacts of relay R-XX04 open, preventing relay R-XX03 from being energized. The normally-open contacts of relay R-XX03 prevent any signal from reaching current-to-pneumatic transducer IP-XX01. Thus, the dampers remain in their normal positions, with outside-air and relief-air dampers closed and return-air damper open.

(2) When the time-clock's occupied contacts close, relays R-XX01 and R-XX02 are energized, and pilot light PL-XX01 is turned on. The contacts of relay R-XX02 energize the supply fan. The auxiliary contacts of the supply-fan starter energize relay R-XX05 and, with the contacts of relay R-XX01, energizes pneumatic valve EP-XX01, which allows the space-temperature controller to control cooling-coil valve VLV-XX02. Temperature-setpoint device TSP-XX01 provides the means for adjusting the setpoint of space-temperature controller TC-XX01.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode of operation, relay R-XX04 is de-energized and pilot light PL-XX02 is turned off. The contacts of relay R-XX04, in series with the now closed but normally-open contacts of relays R-XX01 and R-XX05, energize relay R-XX03. The contacts of relay R-XX03 connect the output signal of high-signal selector TY-XX01 to current-to-pneumatic transducer IP-XX01. The pneumatic output of transducer IP-XX01 places the dampers at minimum position unless relay R-XX06 is energized. Economizer controller EC-XX01 controls the action of relay R-XX06. The economizer receives signals from outside-air temperature transmitter TT-XX01 and from return-air transmitter TT-XX02. The difference between the return-air temperature and the outside-air temperature controls the DEV contacts, and the return-air temperature controls the PV contacts. When both these contacts are closed, relay R-XX06 is energized, and pilot light PL-XX03 is turned on. The

contacts of relay R-XX06 close, allowing the space-temperature controller TC-XX01 signal to modulate the dampers beyond minimum position.

(4) Space-temperature proportional only controller TC-XX01, with its temperature transmitter TT-XX03, on a rise in space temperature modulates the heating-coil valve toward closed. On a further rise in temperature, it modulates the outside-air and relief-air dampers from minimum position toward fully open while modulating the return air damper toward closed. On a still further rise in temperature, the cooling-coil valve is modulated toward fully open. The reverse occurs on a fall in temperature. Whenever the economizer controller de-energizes relay R-XX06, the dampers revert to the minimum position set on minimum position switch MPS-XX01. At the conclusion of the occupied mode, relay R-XX01 is deenergized and, through its contacts, relay R-XX03 is deenergized, closing the dampers; pneumatic valve EP-XX01 de-energized, closing cooling-coil valve VLV-XX02. Heating-coil valve VLV-XX01 is always under the control of temperature controller TC-XX01.

(5) On a fall in temperature to its setpoint, low-temperature-protection thermostat TSL-XX01 opens its set of closed contacts in the supply-fan circuit, de-energizing the supply fan. A set of open contacts in low-temperature-protection thermostat TSL-XX01 closes, energizing relay R-XX07 and lighting pilot light PL-XX05. The contacts of relay R-XX07 energize relay R-XX09. One set of the contacts of relay R-XX09 locks in relay R-XX09, and the other set de-energizes the supply fan. To restart the fan after shutdown, both low-temperature thermostat TSL-XX01 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX02.

(6) When smoke detector SMK-XX01 or smoke detector SMK-XX02 detects the presence of smoke, its normally-closed contacts in the supply-fan starting circuit open, de-energizing the supply fan. The normally-open contacts of the smoke detector(s) close, energizing relay R-XX08 and lighting smoke pilot light PL-XX06. The contacts of relay R-XX08 energize relay R-XX09. One set of the contacts of relay R-XX09 closes to lock in R-XX09, and the other set of contacts, in the supply-fan starter circuit, opens. To restart the fan, the smoke detectors must be manually reset and the HVAC panel must also be reset by depressing momentary switch HS-XX02.

(7) Differential-pressure gauge DPI-XX01 across the filter provides local indication of filter loading. On a rise in pressure drop across the filter to its setpoint, differential-pressure switch DPS-XX01 turns on pilot light PL-XX04.

(8) When the occupied contacts of time clock TC-XX01 open to end the occupied mode and index the system to the unoccupied mode, relays R-XX01 and R-XX02 are de-energized and pilot light PL-XX01 is turned off. The contacts of relay R-XX02 open, de-energizing the supply fan and placing the system's night thermostat TSL-XX02 in control of the supply fan. On a fall in space temperature to 55 degrees F, the contacts of TSL-XX02 close, energizing the fan; on a rise to temperature to 60 degrees

F, the contacts open, de-energizing the fan.

4-24. Dual-temperature-coil single-zone HVAC control system without return fan

a. Description of the HVAC system. This air-handling system consists of a supply fan, economizer dampers, filter, and dual-temperature coil. Figures 4-20A through 4-20F illustrate the design for this type of air-handling system.

b. General sequence of operation.

(1) *Supply fan off* When the fan is off, the outside-air and relief-air dampers are closed and the return-air damper is open. The dual temperature-coil valve is under control.

(2) *Supply fan operating.* when the fan is on, the control dampers and the dual-temperature-coil valve are operated as required by the system's operational modes. The control dampers are positioned for full recirculation of air, positioned to introduce minimum outside air, or modulated to maintain space temperature. The dual-temperature-coil valve is under control.

(3) *Control of supply fan.* Unless the fan is stopped as the result of a safety shutdown, it is on or off as required by the control system mode of operation.

(4) *Safety shutdown of the fan.* The control system shuts down the fan if there is a low-temperature condition or if smoke is detected.

(5) *Low-temperature detection.* On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply fan. To restart the fan, the thermostat and the control panel must be manually reset.

(6) *Smoke detection.* Duct-smoke detectors stop the supply fan whenever either detects the presence of smoke. To restart the fan, the smoke detectors and control panel must be manually reset.

(7) *Filter condition.* Filter condition is monitored by a pressure gauge and a differential-pressure switch. when the rise in pressure drop across the filter reaches the switch setpoint, the switch turns on a pilot light.

(8) *Economizer control.* when the control system's mode of operation no longer requires the outside-air, return-air, and relief-air dampers to be in their full-recirculation positions, the dampers are positioned to admit outside air for ventilation. when both these contacts close, the dampers are modulated as part of the space-temperature control.

(9) *Space-temperature control.* The space-temperature controls have different sequences depending on whether hot water or chilled water is being delivered to the unit dual-temperature coil.

(a) Whenever hot water is being supplied to the unit's dual-temperature coil, on a rise in space temperature, the dual-temperature-coil valve is modulated toward closed. On a further rise through the temperature deadband, the controls make no changes. Then, on a still further rise in space temperature above the deadband, the outside-air and relief-air dampers are modulated from the minimum position toward fully open, and the return-air damper is simultaneously modulated toward closed.

(B) whenever chilled water is being supplied to the

unit's dual-temperature coil, on a rise in space temperature above the deadband, the outside-air and relief-air dampers are modulated from minimum position toward fully open, and simultaneously the return-air damper is modulated toward fully closed and the dual-temperature-coil valve is modulated toward open.

(10) *Unoccupied mode of operation.* During the unoccupied mode throughout the heating season, the supply fan is cycled by the night thermostat to maintain its low-limit space-temperature setpoint, the outside-air and relief-air dampers remain closed, and the return-air damper remains open. During the unoccupied mode in the cooling season, the unit remains de-energized.

(11) *Ventilation-delay mode of operation.* During the ventilation-delay mode, the dampers remain as they were throughout the unoccupied mode, and the supply fan runs continuously. Until the ventilation-delay mode ends, return air is circulated, to bring the building to comfort conditions using a minimum of energy.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode under which the system operates. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay R-XX04 and lighting pilot light PL-XX02. The normally-closed contacts of relay R-XX04 open, preventing relay R-XX03 from being energized. The normally-open contacts of relay R-XX03 prevent any signal from reaching current-to-pneumatic transducer IP-XX01. Thus, the dampers remain in their normal positions, with outside-air and relief-air dampers closed and return-air damper open.

(2) When the time-clock's occupied contacts close, relays R-XX01 and R-XX02 are energized, and pilot light PL-XX01 is turned on. The contacts of relay R-XX02 energize the supply fan. The auxiliary contacts of the supply fan starter energize relay R-XX05.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode, relay R-XX04 is de-energized and pilot light PL-XX02 is turned off. The contacts of relay R-XX04, in series with the now closed but normally-open contacts of relays R-XX01 and R-XX05, energize relay R-XX03. The contacts of relay R-XX03 close between high-signal selector TY-XX01 and current-to-pneumatic transducer IP-XX01; this allows the economizer dampers to assume the position set on minimum-position switch MPS-XX01 unless relay R-XX06 is energized.

(4) Economizer controller EC-XX01 receives signals from outside-air temperature transmitter TT-XX01 and from return-air temperature transmitter TT-XX02. The difference between the return-air temperature and the outside-air temperature controls the DEV contacts, and the return-air temperature controls the PV contacts. when both these contacts are closed, relay R-XX06 is energized and pilot light PL-XX03 is turned on. when relay R-XX06 is energized, its contacts connect the output of space-temperature controller TC-XX02 to high signal selector TY-XX01, to modulate the outside-air and return-air

dampers between minimum position and fully open while modulating the return-air damper in the opposite direction to maintain the temperature controller setpoint.

(5) Space-temperature transmitter TT-XX03 signals the space temperature to controllers TC-XX01 and TC-XX02. Controllers TC-XX01 and TC-XX02 are proportional only controllers. Temperature setpoint device TSP-XX01 provides the means for adjusting the setpoints of space zone temperature controllers, TC-XX01 and TC-XX02. On a rise in temperature during the heating season when hot water is being supplied to the dual-temperature coil, space-temperature controller TC-XX02 modulates the dual-temperature-coil valve VLV-XX01 toward closed. On a further rise in space temperature through the temperature deadband, the controller is inactive. On a still further rise in space temperature, economizer controller permitting, controller TC-XX02 modulates the outside-air and relief-air dampers from the minimum position set on minimum position switch MPS-XX01 toward fully open, and simultaneously modulates the return-air damper toward closed.

(6) On a fall in temperature to its setpoint, changeover aquastat TS-XX01 in the dual-temperature water supply energizes electrically-actuated pneumatic valve EP-XX01, which interrupts the TC-XX02/IP-XX02 signal to dual-temperature-coil valve VLV-XX01 and replaces it with the reverse acting. TC-XX01/P-XX03 signal. In addition, TS-XX01 energizes changeover relay R-XX10 when relay R-XX10 is energized its contacts turn off heating pilot light PL XX07 and turn on cooling pilot light PL-XX08 On a rise in space temperature during the cooling season, temperature controller TC-XX02, economizer controller permitting, modulates the outside-air and relief-air dampers AD-XX01 and AD-XX03 from minimum position toward fully open and simultaneously modulates the return-air damper AD-XX02 toward fully closed. Controller TC-XX01, through current-to-pneumatic transducer IP-XX03, modulates dual-temperature-coil valve VLV-XX01 toward open.

(7) On a fall in temperature to its setpoint, low-temperature-protection thermostat TSL-XX01 opens a set of closed contacts in the supply-fan circuit, de-energizing the supply fan. A set of open contacts in low-temperature-protection thermostat TSL-XX01 closes, energizing relay R-XX07 and lighting pilot light PL-XX05. The contacts of relay R-XX07 energize R-XX09. One set of the contacts of relay R-XX09 locks in relay R-XX09 and the other set de-energizes the supply fan. To restart the fans after a low-temperature shutdown both the low-temperature thermostat TSL-XX01 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HX-XX02.

(8) When smoke detector SMK-XX01 or smoke detector SMK-XX02 detects the presence of smoke, its normally-closed contacts in the supply-fan starting circuit open, de-energizing the supply fan. The normally-open contacts of the smoke detector(s) close, energizing relay R-XX08 and lighting smoke pilot PL-XX06. The contacts of relay R-XX08 energize relay R-XX09. One set of the

contacts of relay R-XX09 closes to lock in R-XX09, and the other set of contacts, in the supply-fan starter circuit, opens. To restart the fan, the smoke detectors must be manually reset and the HVAC panel must also be reset by momentarily depressing manual switch HS-XX02.

(9) Differential-pressure gauge DPI-XX01 across the filter gives local indication of filter loading. On a rise in pressure drop across the filter to its setpoint, differential-pressure switch DPS-XX01 turns on pilot light PL-XX04.

(10) When the occupied contacts of time clock CLK-XX01 open to end the occupied mode and index the system to the unoccupied mode, relays R-XX01 and R-XX02 are de-energized and pilot light PL-XX01 is turned off. The contacts of relay R-XX02 open, de-energizing the supply fan and placing the system's night thermostat TSL-XX02 in control of the supply fan. On a fall in space temperature to 55 degrees F, the contacts of TSL-XX02 close, energizing the fan; on a rise in temperature to 60 degrees F, the contacts open, de-energizing the fan.

4-25. Single-zone HVAC control system with humidity control without return fan

a. Description of the HVAC system. This air-handling system consists of a supply fan, filter, preheat coil, cooling coil, reheat coil, and humidifier. The system also has a steam-to-water heat exchanger and pump to supply hot water to the preheat and reheat coils. Figures 4-21A through 4-2 1F illustrates the design for this type of air-handling system.

b. General sequence of operation.

(1) *Supply fan off.* When the fan is off, the outside-air damper and the cooling-coil, humidifier and heat-exchanger valves are all closed, and the pump is off. The reheat coil valve remains under space temperature control.

(2) *Supply fan operating.* When the fan is on, the pump is on, and the outside-air damper, heat-exchanger valve, preheat-coil valve, cooling-coil valve, reheat-coil valve and humidifier valve are operated as required by the system's operational modes. The outside-air damper is either open or closed. The preheat coil and reheat coil valves are under the control of their respective controllers. The cooling-coil valve is either closed or modulated to maintain the space temperature and/or humidity.

(3) *Control of supply fan.* Unless the fan is stopped as the result of a safety shutdown, it is on or off as required by the control system's mode of operation.

(4) *Safety shutdown of the fan.* The control system shuts down the fan if there is a low-temperature condition, or if smoke is detected.

(5) *Low-temperature detection.* On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply fan. To restart the fan, the thermostat and the control panel must be manually reset.

(6) *Smoke detection.* Duct-smoke detectors stop the supply fan whenever they detect the presence of smoke. To restart the fan, the smoke detectors and control panel must be manually reset.

(7) *Filter condition.* Filter condition is monitored by a pressure gauge and a differential-pressure switch. when the rise in pressure drop across the filter reaches the switch setpoint, the switch turns on a pilot light.

(8) *Preheat-coil control.* The preheat-coil valve is modulated to maintain a constant preheat-coil discharge temperature.

(9) *Space-temperature control.* The reheat-coil valve and cooling-coil valve are modulated in sequence to maintain a constant space temperature.

(10) *Space-humidity control.* The humidifier valve and cooling-coil valve are modulated in sequence to maintain a constant relative humidity in the space. A high-limit unit-discharge humidity control overrides the space control of the humidifier valve when necessary, to prevent the relative humidity in the supply duct from exceeding its high-limit setpoint.

(11) *Unoccupied mode of operation.* Throughout the unoccupied mode, the outside-air damper and cooling-coil valve remain closed. The supply fan is cycled by the night thermostat to maintain its low-limit space-temperature setpoint.

(12) *Ventilation-delay mode of operation.* Throughout the ventilation-delay mode, the outside-air damper remains closed. The reheat-coil and cooling-coil valves are under the control of the room temperature controller. Return air is circulated, to bring the building to comfort conditions, using a minimum of energy.

(13) *Occupied mode of operation.* The supply fan runs continuously with the outside-air dampers open. The space temperature and humidity are controlled as previously described.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode under which the system operates. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay R-XX04 and lighting ventilation-delay pilot light PL-XX02. The closed contacts of relay R-XX04 open, preventing relay R-XX03 and electrically-actuated pneumatic valve EP-XX01 from being energized. The open contacts of relay R-XX03 interrupt the signal to IP-XX03 keeping the humidifier valve closed. when EP-XX01 is de-energized, the damper remains closed.

(2) When the occupied contacts of time-clock CLK-XX01 close, relays R-XX01 and R-XX02 are energized and pilot light PL-XX01 is turned on. The contacts of relay R-XX01 energize the supply fan. The auxiliary contacts of the supply-fan starter energize relay R-XX05, and since R-XX01 is already energized it also energizes relay R-XX06. The contacts of relay R-XX05 energize the pump starter, and the contacts of relay R-XX06 place the cooling-coil valve under space temperature/humidity control.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode of operation, relay R-XX04 is de-energized. The normally-closed contacts of relay R-XX04 is close, energizing relay

R-XX03 and pneumatic valve EP-XX01. Pneumatic valve EP-XX01 opens the outdoor-air damper. The contacts of relay R-XX03 place the humidifier valve under control as described in paragraph 4-25.c.(10).

(4) On a rise in differential pressure to its setpoint, differential-pressure switch DPS-XX01 or DPS-XX02 lights the filter pilot light PL-XX03.

(5) On a fall in temperature to its setpoint, the closed contacts of low-temperature-protection thermostat TSL-XX01 open, de-energizing the fan; its open contacts close, energizing relay R-XX07 and lighting low-temperature pilot light PL-XX04. The contacts of relay R-XX07 energize shutdown relay R-XX09. One set of the contacts of relay R-XX09 closes to lock relay R-XX09 in, and the other set de-energizes the supply fan. To restart the fan, the thermostat and the control panel both must be reset. Momentary switch HS-XX02 is used to reset the panel.

(6) When either smoke detector SMK-XX01 or SMK-XX02 detects the presence of smoke, its normally-closed contacts in the supply-fan starting circuit open, de-energizing the supply fan. The normally-open contacts of the smoke detector(s) close, energizing relay R-XX08 and lighting smoke pilot light PL-XX05. The contacts of relay R-XX08 energize relay R-XX09. One set of the contacts of relay R-XX09 close to lock in R-XX09, and the other set of contacts, in the supply-fan starter circuit, opens to de-energize the fan. To restart the fan, the smoke detectors must be manually reset and the HVAC panel must also be reset by depressing momentary switch HS-XX02.

(7) Whenever the pump runs, the auxiliary contacts of the pump starter energize relay R-XX10 and light heating pilot light PL-XX06. The contacts of relay R-XX10 place heat-exchanger valve VLV-XX05 under control.

(8) Temperature transmitter T-T-XX01 signals the preheat-coil discharge temperature to temperature controller TC-XX01. The output of TC-XX01 is received by current-to-pneumatic transducer IP-XX01. The pneumatic output of IP-XX01 modulates the preheat-coil valve VLV-XX01 to maintain the setpoint of controller TC-XX01.

(9) Space-temperature transmitter TT-XX02 signals the space-temperature to temperature controller TC-XX02. The output of TC-XX02 is received by current-to-pneumatic transducer IP-XX04 and high-signal selector TY-XX01. The pneumatic output of current-to-pneumatic transducer IP-XX04 modulates the reheat-coil valve VLV-XX03. High-signal selector TY-XX01 passes the higher of the temperature signal and the humidity signal (next paragraph) during the ventilation-delay and occupied modes to current-to-pneumatic transducer IP-XX02. The pneumatic signal of IP-XX02 modulates the cooling-coil valve VLV-XX02 to maintain the space temperature or humidity setpoint.

(10) Space-humidity transmitter RHT-XX02 signals the space relative humidity to relative humidity controller RHC-XX02. The output of relative-humidity controller RHC-XX02 is transmitted to low-signal selector RHY-XX01 and inverter INV-XX01. Low-signal selector RHY-XX01 also receives a signal from unit-discharge high-limit

humidity controller RHC-XX01, (must be proportional only) which receives unit-discharge relative-humidity signals from unit-discharge relative-humidity transmitter RHT-XX01. The output of RHY-XX01, during the occupied mode only, is received by current-to-pneumatic transmitter IP-XX03, and the pneumatic output of IP-XX03 modulates humidifier steam valve VLV-XX04. The signal from controller RHC-XX02 to inverter INV-XX01 is reversed and sent to high-signal selector TY-XX01. The signal from space-temperature controller TC-XX02, (previous paragraph) and the signal from space-relative-humidity controller RHC-XX02, after inversion are compared, and the higher signal, during the ventilation delay and occupied modes, is sent to current-to-pneumatic transducer IP-XX02. The pneumatic signal of IP-XX02 modulates the cooling-coil valve VLV-XX02 to maintain the space-temperature or humidity setpoint.

(11) Temperature transmitter IT-XX03 in the heat-exchanger discharge, signals the hot-water supply temperature to temperature controller TC-XX03. whenever the pump runs, relay R-XX10 is energized, and, through the contacts of R-XX10, the output of TC-XX03, through current-to-pneumatic transducer IP-XX05, modulates heat-exchanger valve VLV-XX05 to maintain the TC-XX03 temperature setpoint. when the pump is deenergized, the contacts of relay R-XX10 open, and the valve closes.

(12) When the occupied contacts of CLK-XX01 open to end the occupied mode and index the system to the unoccupied mode, relay R-XX01 is de-energized and pilot light PL-XX01 is turned off. The contacts of relay R-XX01 open, de-energizing the supply fan and placing the system's night thermostat TSL-XX02 in control of the supply fan. On a fall in space temperature to 55 degrees F, the contacts of TSL-XX02 close, energizing the fan; on a rise in temperature to 60 degrees F, the contacts open, de-energizing the fan.

4-26. Single-zone HVAC control system with direct-expansion (DX) cooling coil without return fan

a. Description of the HVAC system. This air-handling system consists of a supply fan, economizer dampers, filter, heating coil, and a three-stage direct-expansion cooling coil. Figures 4-22A through 4-22F illustrate the design for this type of air-handling system.

b. General sequence of operation.

(1) *Supply fan off* when the fan is off, the outside-air and relief-air dampers are closed and the return-air damper is open. The heating-coil valve is under control.

(2) *Supply fan operating.* when the fan is on, the control dampers are either positioned for full recirculation of air, positioned to introduce minimum outside air, or modulated to maintain space temperature. The cooling is either deenergized or cycled in stages to maintain space temperature.

(3) *Control of supply fan.* Unless the fan is stopped as the result of a safety shutdown, it is on or off as required by the control system's mode of operation.

(4) *Safety shutdown of the fan.* The control system

shuts down the fan *if* there is a low-temperature condition, or if smoke is detected.

(5) *Low-temperature detection.* On a fall in temperature to its setpoint, a low-temperature-protection thermostat stops the supply fan. To restart the fan, the thermostat and the control panel must be manually reset.

(6) *Smoke detection.* Duct smoke detectors stop the supply fan whenever they detect the presence of smoke. To restart the fan, the smoke detectors and control panel must be manually reset.

(7) *Filter condition.* Filter condition is monitored by a pressure gauge and a differential-pressure switch. when the rise in pressure drop across the filter reaches the switch setpoint, the switch turns on a pilot light.

(8) *Economizer control.* When the control system's mode of operation no longer requires the outside-air, return-air, and relief-air dampers to be in their full-recirculating positions, the dampers are positioned to admit outside air for ventilation. The amount of ventilation air then remains at minimum until the economizer controller closes both its PV and DEV contacts. The economizer controller closes its PV contacts when the return-air temperature indicates that the building requires cooling rather than heating. The economizer controller closes its DEV contacts when the outside-air temperature is sufficiently below the return-air temperature to be effective for cooling. when both these contacts close, the dampers are modulated as part of the space-temperature control.

(9) *Space-temperature control.* On a rise in space temperature, the heating-coil valve is modulated toward closed. On a further space temperature rise, the outside-air and relief-air dampers are modulated between minimum position toward fully open, and simultaneously the return air damper is modulated toward fully closed to maintain space temperature. On a still further rise in temperature, the stages of cooling are cycled to maintain the space temperature.

(10) Unoccupied mode of operation. Throughout the unoccupied mode, the outside-air and relief-air dampers

remain closed, and the return-air damper remains open. The heating-coil valve remains under space-temperature control. The cooling stages are de-energized. The supply fan is cycled by the system's night thermostat to maintain its low-limit space-temperature setpoint.

(11) Ventilation-delay mode of operation. During the ventilation-delay mode, the dampers remain as they were throughout the unoccupied mode, and the supply fan runs continuously. The cooling system is enabled. Until the ventilation-delay mode ends, return air is circulated, to bring the building to comfort conditions, using a minimum of energy.

(12) Occupied mode of operation. The supply fan runs continuously, and the outside-air and relief-air dampers are at minimum position or are under space-temperature control as previously described.

c. Detailed sequence of operation.

(1) Time clock CLK-XX01 has two independent sets of contacts, which between them determine the mode under which the system operates. Five minutes before the scheduled beginning of the occupied mode, the ventilation-delay contacts close, energizing relay R-XX04 and lighting pilot light PL-XX02. The normally-closed contacts of relay R-XX04 open, preventing relay R-XX03 from being energized. The normally-open contacts of relay R-XX03 prevent any signal from reaching electric damper actuators DA-XX01, DA-XX02, and DA-XX03. Thus, the dampers remain in their normal positions, with outside-air and relief-air dampers closed and return-air damper open.

(2) When the time-clock's occupied contacts close, relays R-XX01 and R-XX02 are energized, and occupied pilot light PL-XX01 is turned on. The contacts of relay R-XX02 energize the supply fan. The auxiliary contacts of the supply-fan starter energize relay R-XX05 and, with the contacts of relay R-XX01, energize relay R-XX06, which places the space-temperature controller TC-XX01 in control of cooling sequencer SQCR-XX01.

(3) When the ventilation-delay contacts of time clock CLK-XX01 open to end the ventilation-delay mode, relay

R-XX04 is de-energized and pilot light PL-XX02 is turned off. The contacts of relay R-XX04 energize relay R-XX03. The contacts of relay R-XX03 close between high-signal selector TY-XX01 and the electric-damper actuators. This allows the economizer dampers to assume the position set on minimum-position switch MPS-XX01 unless relay R-XX07 is energized.

(4) Economizer controller EC-XX01 receives signals from outside-air temperature transmitter '–,T-XX01 and from return-air temperature transmitter TT-XX02. The difference between the return-air temperature and the outside-air temperature controls the DEV contacts, and the return-air temperature controls the PV contacts. when both these contacts are closed, relay R-XX07 is energized and pilot light PL-XX03 is turned on. when relay R-XX07 is energized, its contacts connect the output of space-temperature controller TC-XX01 to high-signal selector TY-XX01, to modulate the outside-air and return-air dampers between minimum position and fully open while modulating the return-air damper in the opposite direction to maintain the temperature controller setpoint.

(5) Space-temperature transmitter TT-XX03 signals the space temperature to proportional only space-temperature controller TC-XX01. The TC-XX01 output through loop drivers LD-XX01, LD-XX02, and LD-XX03 controls the cooling sequencer, the economizer dampers, and the heating-coil valve respectively. On a rise in space temperature, controller TC-XX01 through loop driver LD-XX03 modulates heating-coil valve VLV-XX01 closed. On a further temperature rise, if the economizer controller permits, the controller, through loop driver LD-XX02, modulates the outside-air and relief-air dampers from minimum position toward fully open and simultaneously modulates the return-air damper toward fully closed. On a still further rise, the controller, through loop driver LD-XX01 and sequencer SQCR-XX01, successively energizes the stages of cooling. The reverse occurs on a fall in temperature.

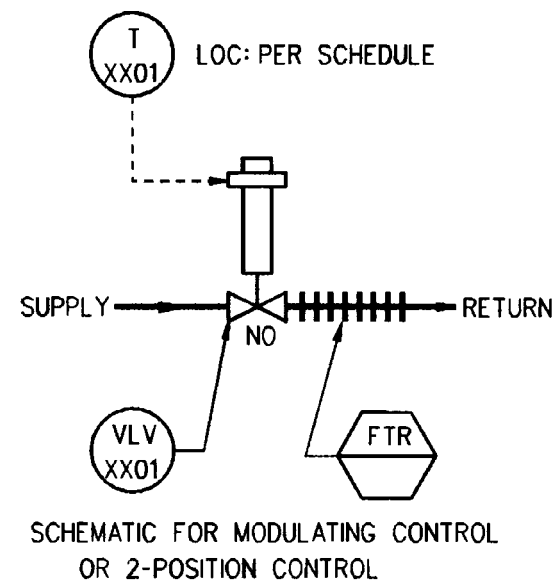
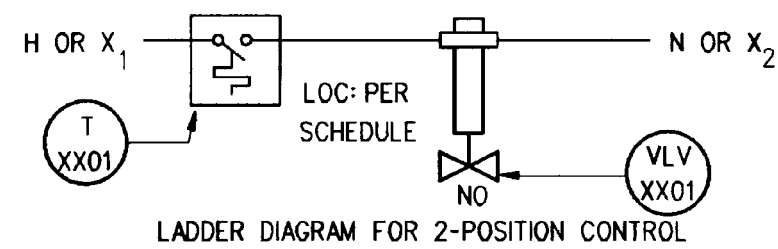
(6) On a fall in temperature to its setpoint, low-

temperature-protection thermostat TSL-XX01 opens a set of closed contacts in the supply-fan circuit, de-energizing the supply fan. A set of open contacts in low-temperature-protection thermostat TSL-XX01 closes, energizing relay R-XX08 and lighting low-temperature pilot light PL-XX05. The contacts of R-XX08 energize relay R-XX10. One set of the contacts of relay R-XX10 locks in relay R-XX10, and the other set de-energizes the supply fan. To restart the fans after a low-temperature shutdown both the low-temperature thermostat TSL-XX01 and the control panel must be manually reset. The control panel is reset by momentarily depressing manual switch HS-XX02.

(7) When smoke detector SMK-XX01 or smoke detector SMK-XX02 detects the presence of smoke, its normally-closed contacts in the supply-fan starting circuit open, de-energizing the supply fan. The normally-open contacts of the smoke detector(s) close, energizing relay R-XX09 and lighting smoke pilot light PL-XX06. The contacts of relay R-XX09 energize relay R-XX10. One set of the contacts of relay R-XX10 closes to lock in R-XX10, and the other set of contacts, in the supply-fan starter circuit, opens. To restart the fan, the smoke detectors must be manually reset and the HVAC panel must also be reset by depressing momentary switch HS-XX02.

(8) Differential-pressure gauge DPI-XX01 across the filter provides local indication of filter loading. On a rise in pressure drop across the filter to its setpoint, differential-pressure switch DPS-XX01 turns on pilot light PL-XX04.

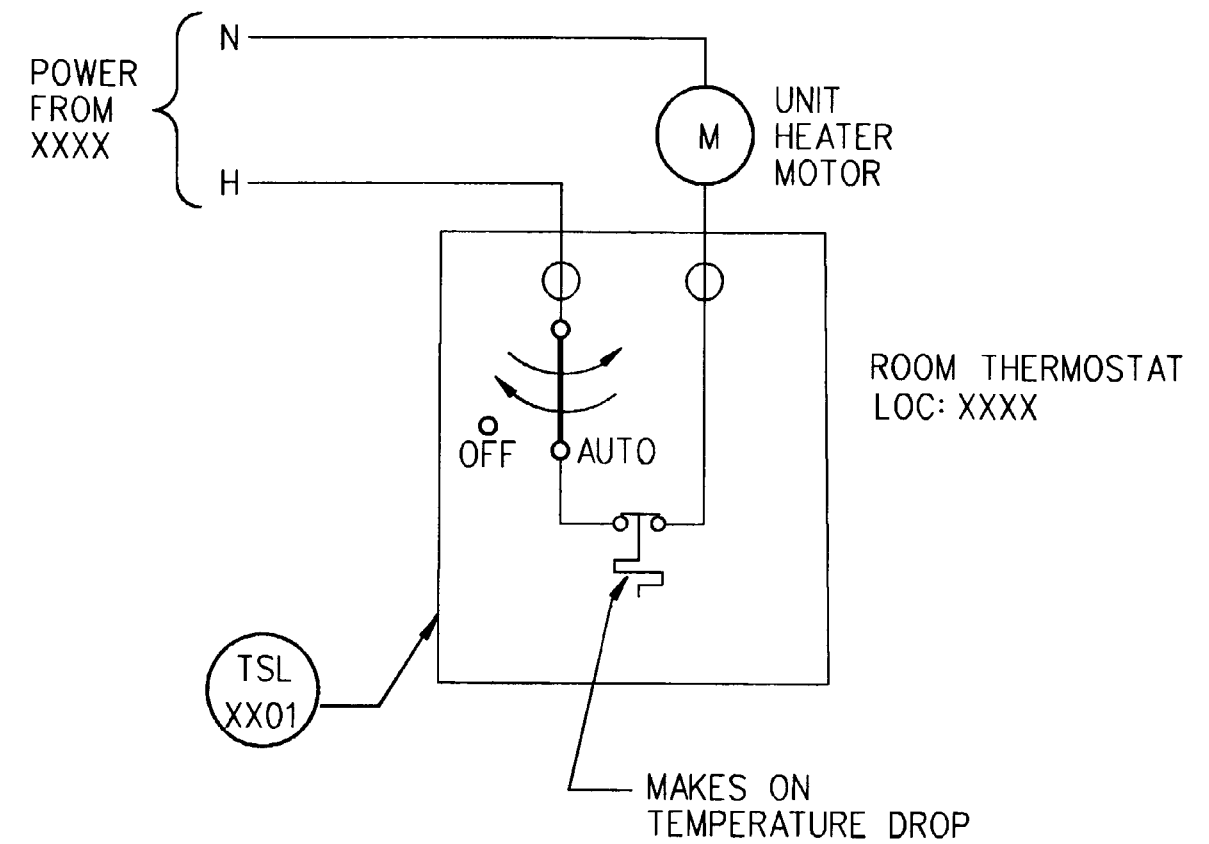
(9) When the occupied contacts of time clock CLK-XX01 open to end the occupied mode and index the system to the unoccupied mode, relays R-XX01 and R-XX02 are de-energized and pilot light PL-XX01 is turned off. The contacts of relay R-XX02 open, de-energizing the supply fan and placing the system's night thermostat TSL-XX02 in control of the supply fan. On a fall in space temperature to 55 degrees F, the contacts of TSL-XX02 close, energizing the fan; on a rise in temperature to 60 degrees F, the contacts open, de-energizing the fan.



SPACE	FTR	THERMOSTAT	VALVE	REMARKS
XXXX	XX	T-XX01 SET: 68°F	VLV-XX01	CV=0.2 CLOSE AGAINST 10 PSIG
.
YYYY	YY	T-XXXX SET: 68°F	VLV-XXXX	CV=0.7 CLOSE AGAINST 10 PSIG

EQUIPMENT SCHEDULE

Figure 4-1. Space-temperature-controlled perimeter-radiation control system XX.

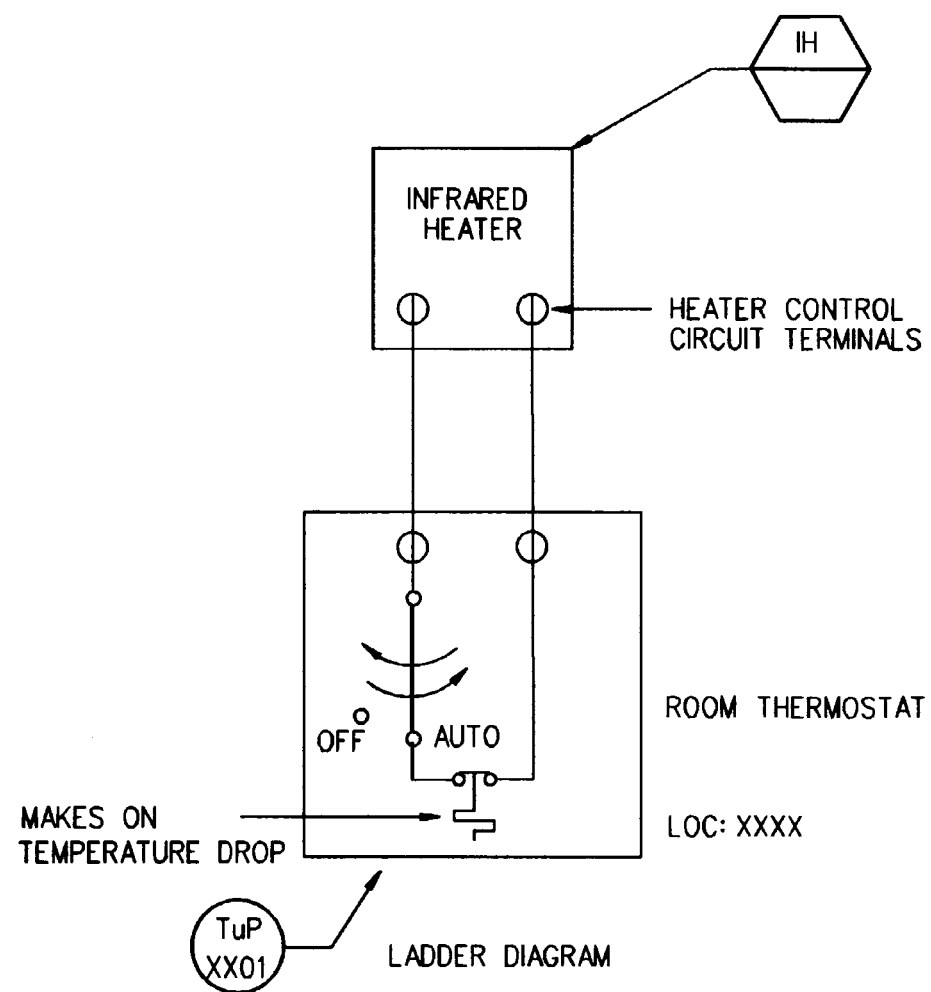


LADDER DIAGRAM

SPACE	UH	THERMOSTAT
XXXX	XX	TSL-XX01 SET: 55°F
.	.	.
YYYY	YY	TSL-XXXX SET: 55°F

EQUIPMENT SCHEDULE

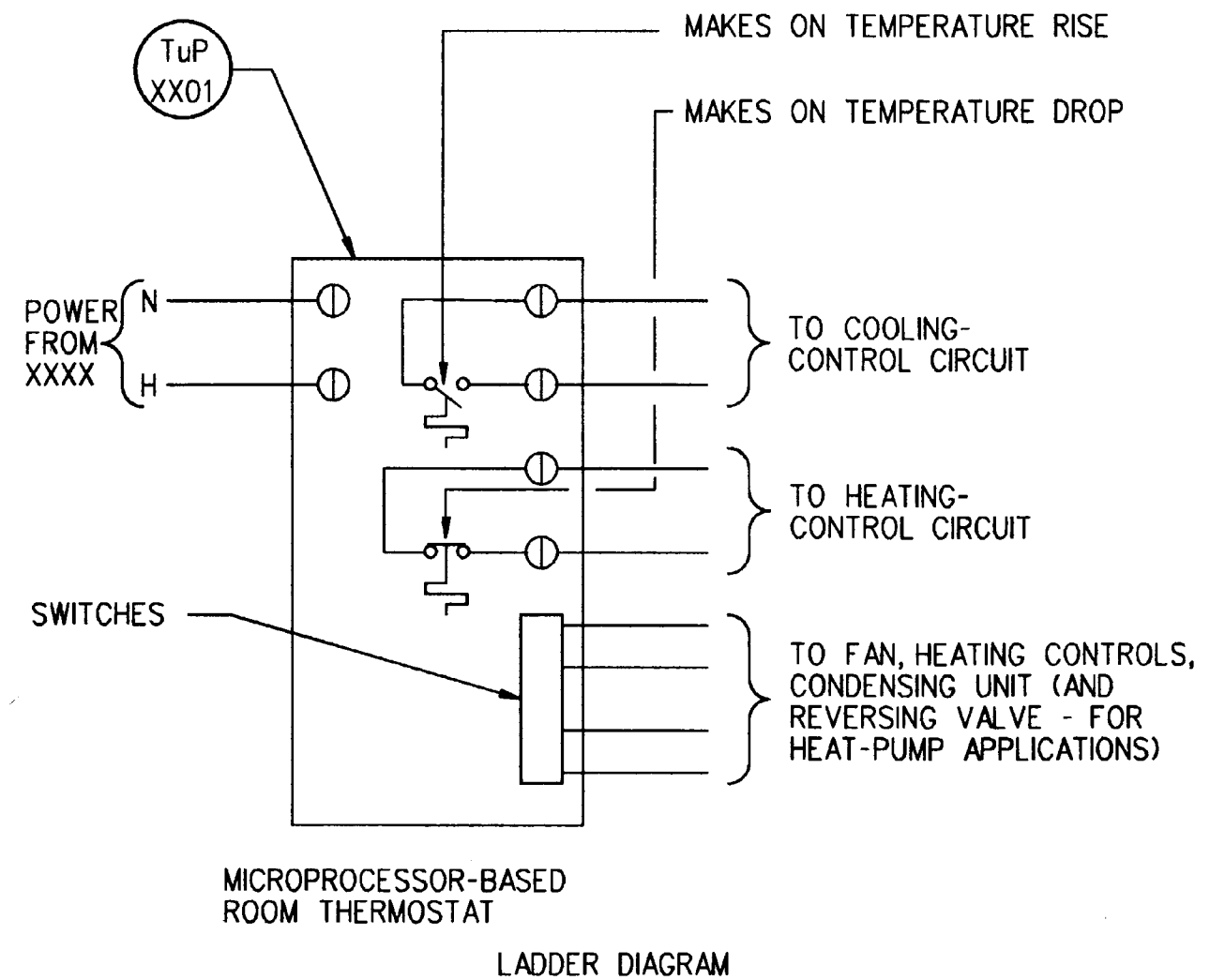
Figure 4-2. Unit-heater temperature-control system XX.



SPACE	IH	THERMOSTAT	OCCUPIED MODE
XXXX	XY	TuP-XX01 SET: 68°F-DAY 55°F-NIGHT	M,T,W,TH,F 0830 HRS TO 1730 HRS
.	.	.	
YXXY	YY	TuP-XXXX SET: 68°F-DAY 55°F-NIGHT	SUNDAY 0830 HRS 1200 HRS

EQUIPMENT SCHEDULE

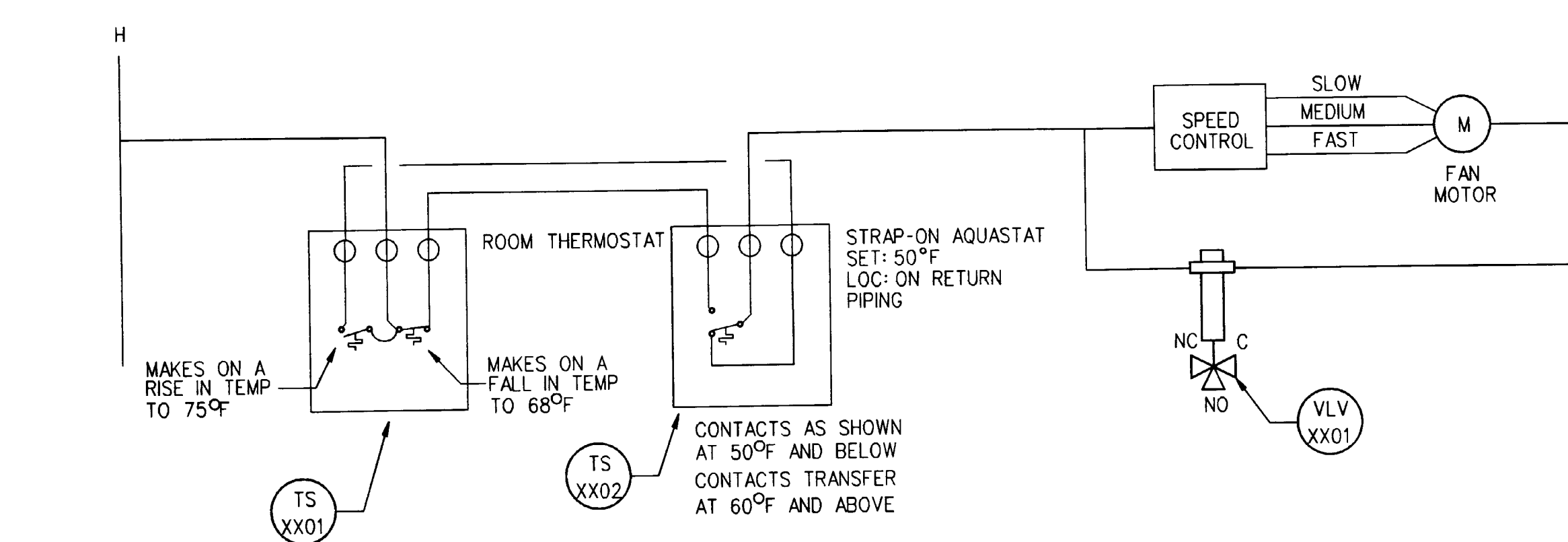
Figure 4-3. Gas-fired infrared-heater temperature control system XX.



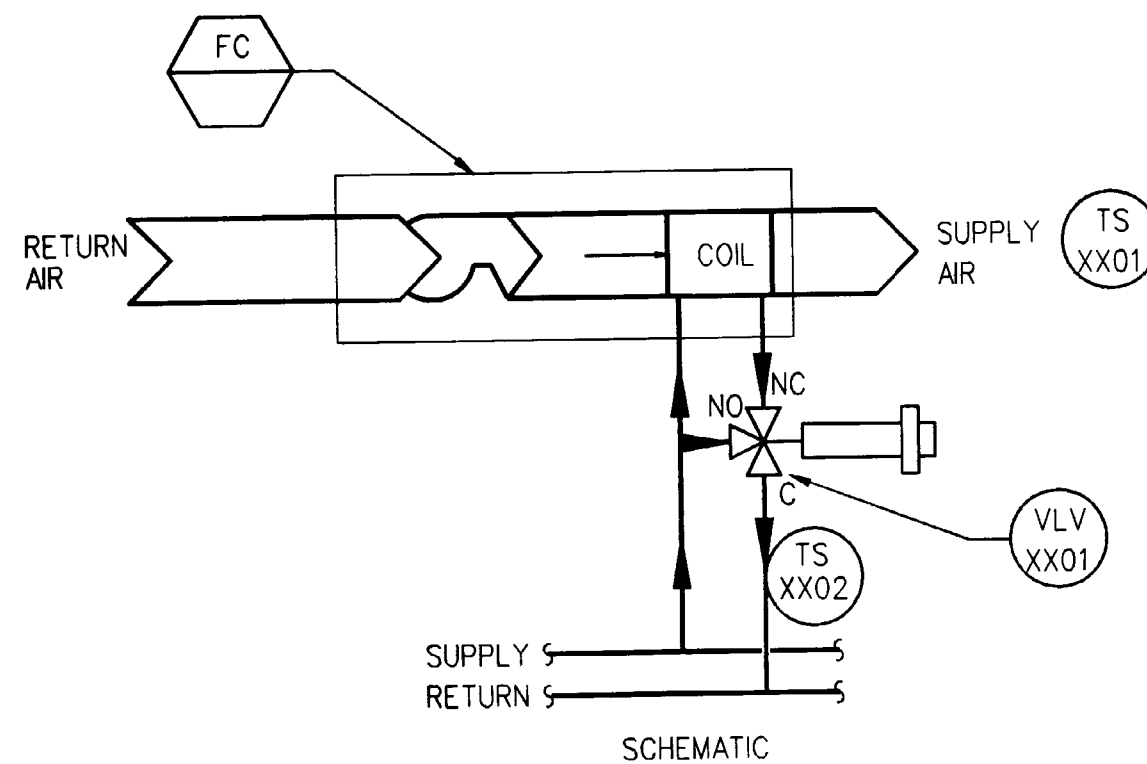
SPACE	AC	THERMOSTAT	OCCUPIED MODE
XXXX	XY	TUP-XX01 SET: 68°F - DAY HEATING 55°F - NIGHT HEATING 78°F - DAY COOLING OFF - NIGHT COOLING	M,T,W,TH,F 0830 HRS TO 1730 HRS

EQUIPMENT SCHEDULE

Figure 4-4. All-air small-package unitary-system control system XX.



LADDER DIAGRAM

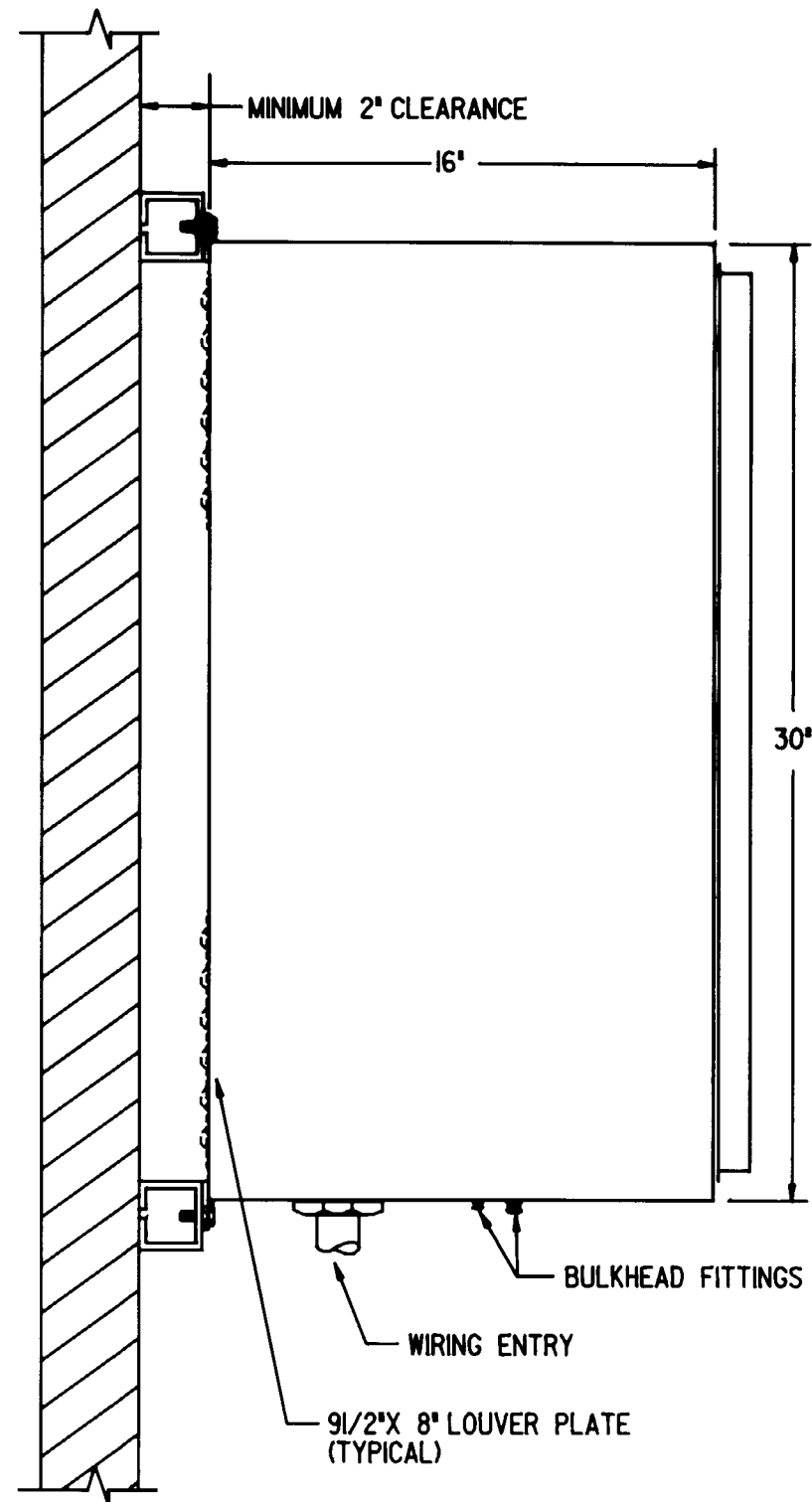


SCHEMATIC

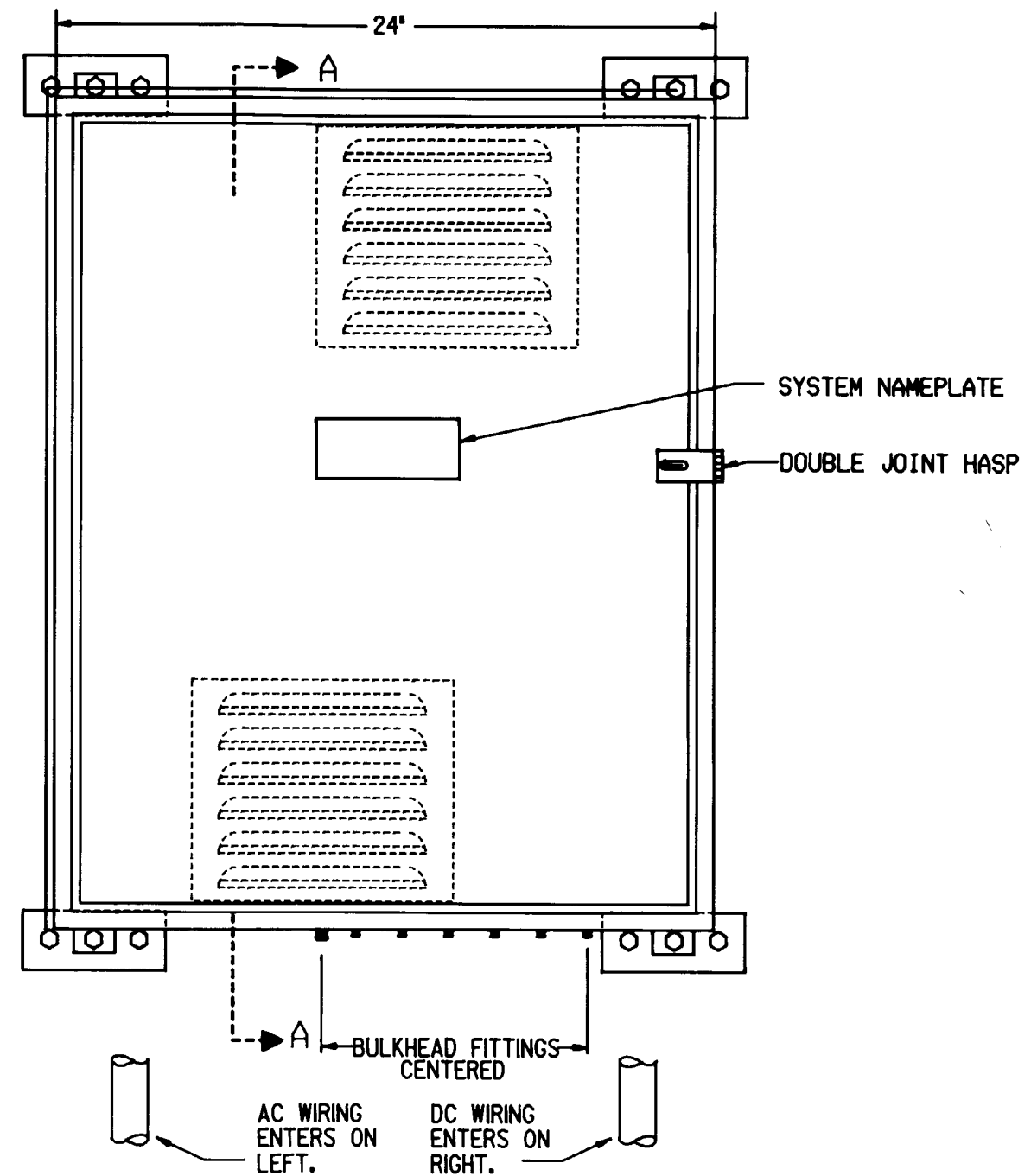
SPACE	FC	THERMOSTAT	AQUASTAT	VALVE AND ACTUATOR	REMARKS
XXXX	XX	TS-XX01 SET: 68°F HEATING SET: 75°F COOLING	TS-XX02 SET: 50°F	VLV-XX01	CV=2 CLOSE AGAINST 10 PSIG
...
ZZZZ	ZZ	TS-XXXX SET: 68°F HEATING SET: 75°F COOLING	TS -XXXY SET: 50°F	VLV-XXXX	CV=1.2 CLOSE AGAINST 10 PSIG

EQUIPMENT SCHEDULE

Figure 4-5. Dual-temperature fan-coil-unit temperature control system XX.



SIDE VIEW



FRONT VIEW

Figure 4-6A. Standard wall-mounted HVAC control-panel arrangement.

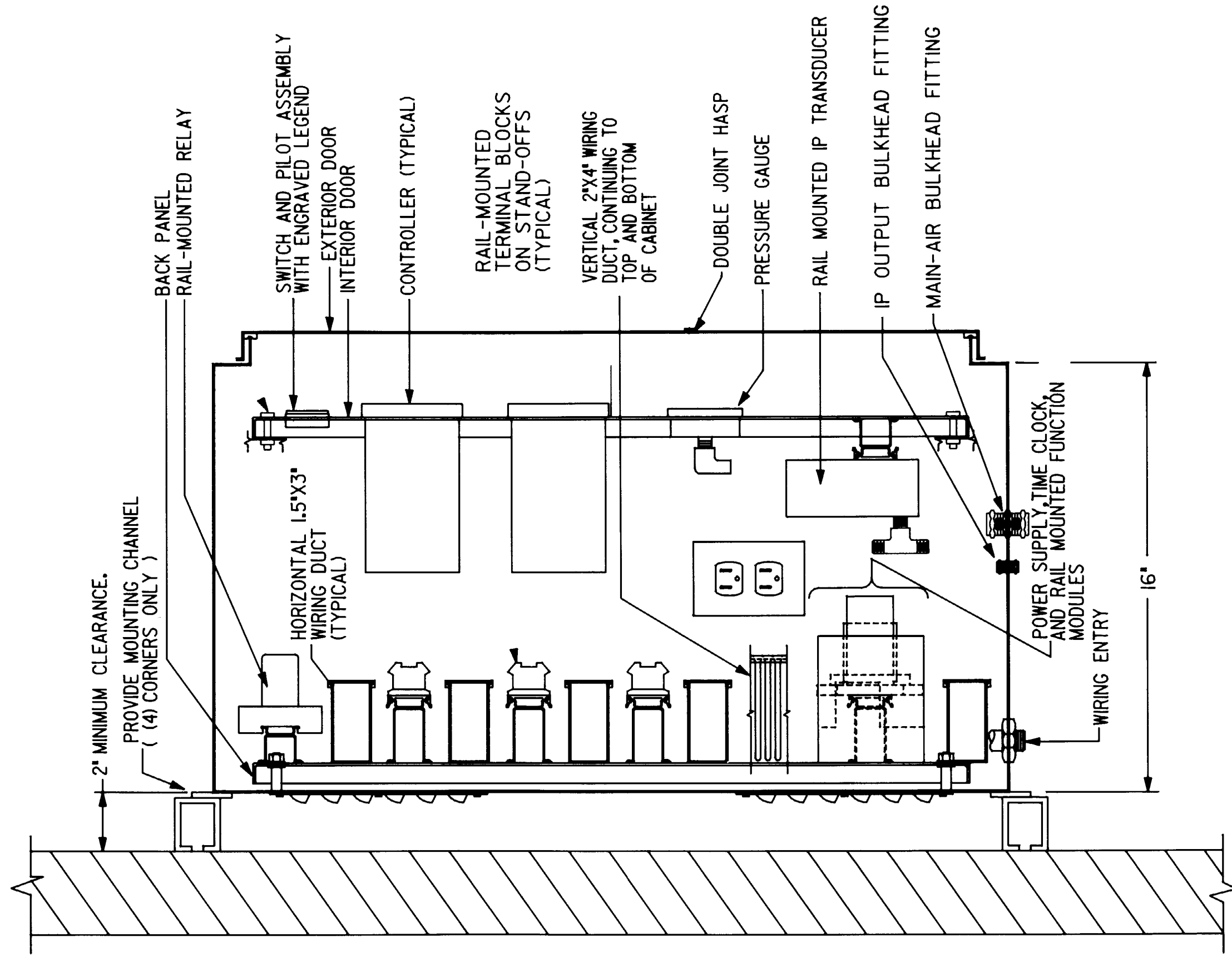
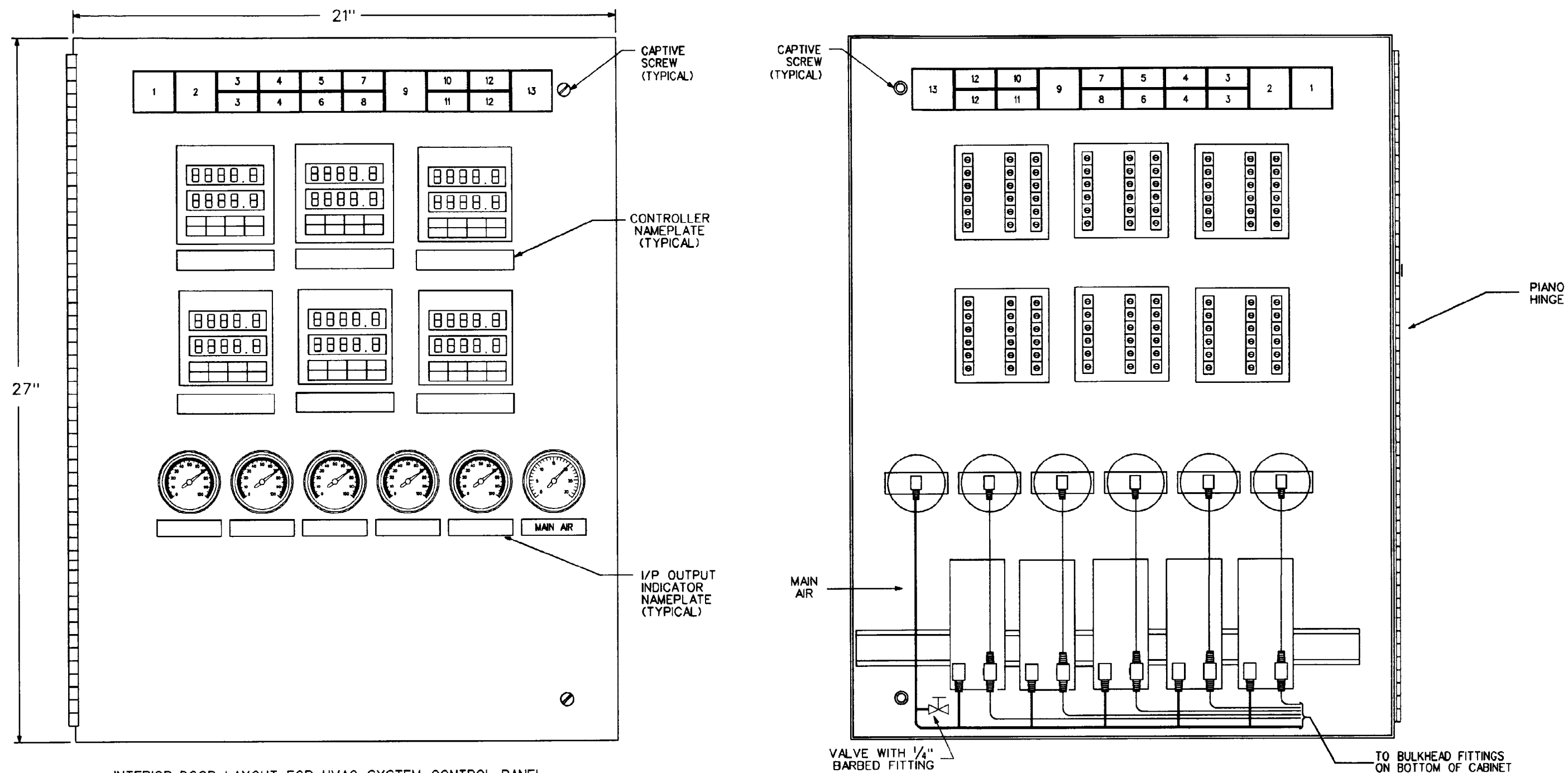


Figure 4-6B. Section "A-A" through the standard HVAC control panel.



INTERIOR-DOOR LAYOUT FOR HVAC SYSTEM CONTROL PANEL
(FRONT VIEW)

SWITCH AND PILOT LIGHT LEGEND

INTERIOR-DOOR LAYOUT FOR HVAC SYSTEM CONTROL PANEL
(REAR VIEW)

POSITION LEGEND	DEVICE TYPE
1 - RESET	NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH
2 - STATIC RESET	NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH
3 - AUTO/AUTO OVERRIDE	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES
4 - ENABLE/OFF	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES

POSITION LEGEND	DEVICE TYPE
5 - LOW TEMP	PILOT LIGHT
6 - SMOKE	PILOT LIGHT
7 - HIGH STATIC	PILOT LIGHT
8 - FILTER	PILOT LIGHT

POSITION LEGEND	DEVICE TYPE
9 - OCC	PILOT LIGHT
10 - VENT DELAY	PILOT LIGHT
11 - ECON	PILOT LIGHT
12 - HEAT/COOL	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES
13 -	ASSIGNABLE

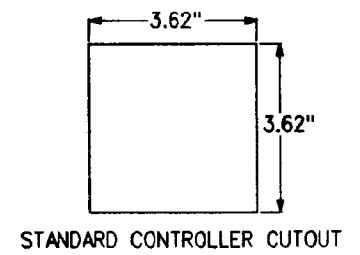


Figure 4-6C. Standard HVAC control-panel interior door.

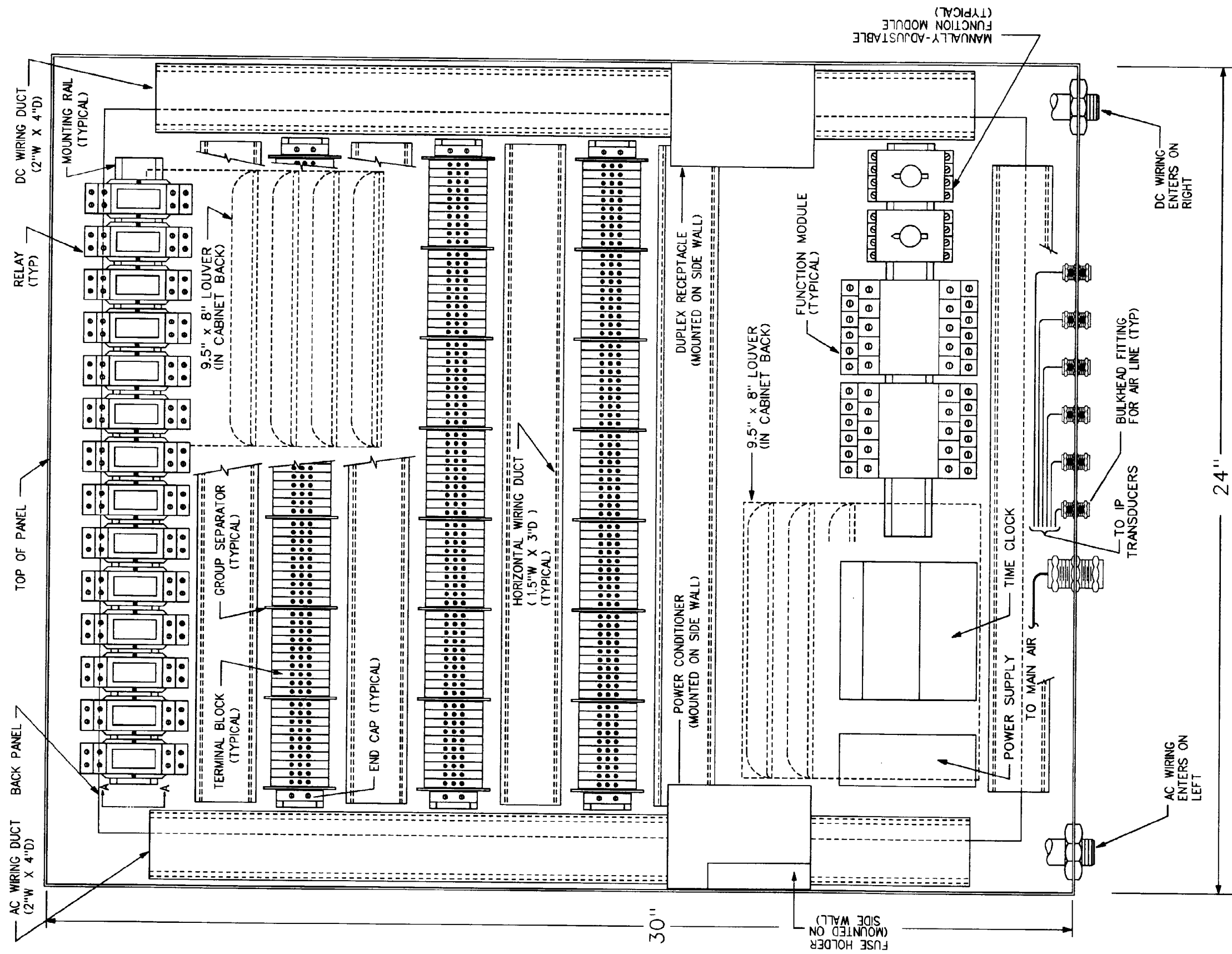


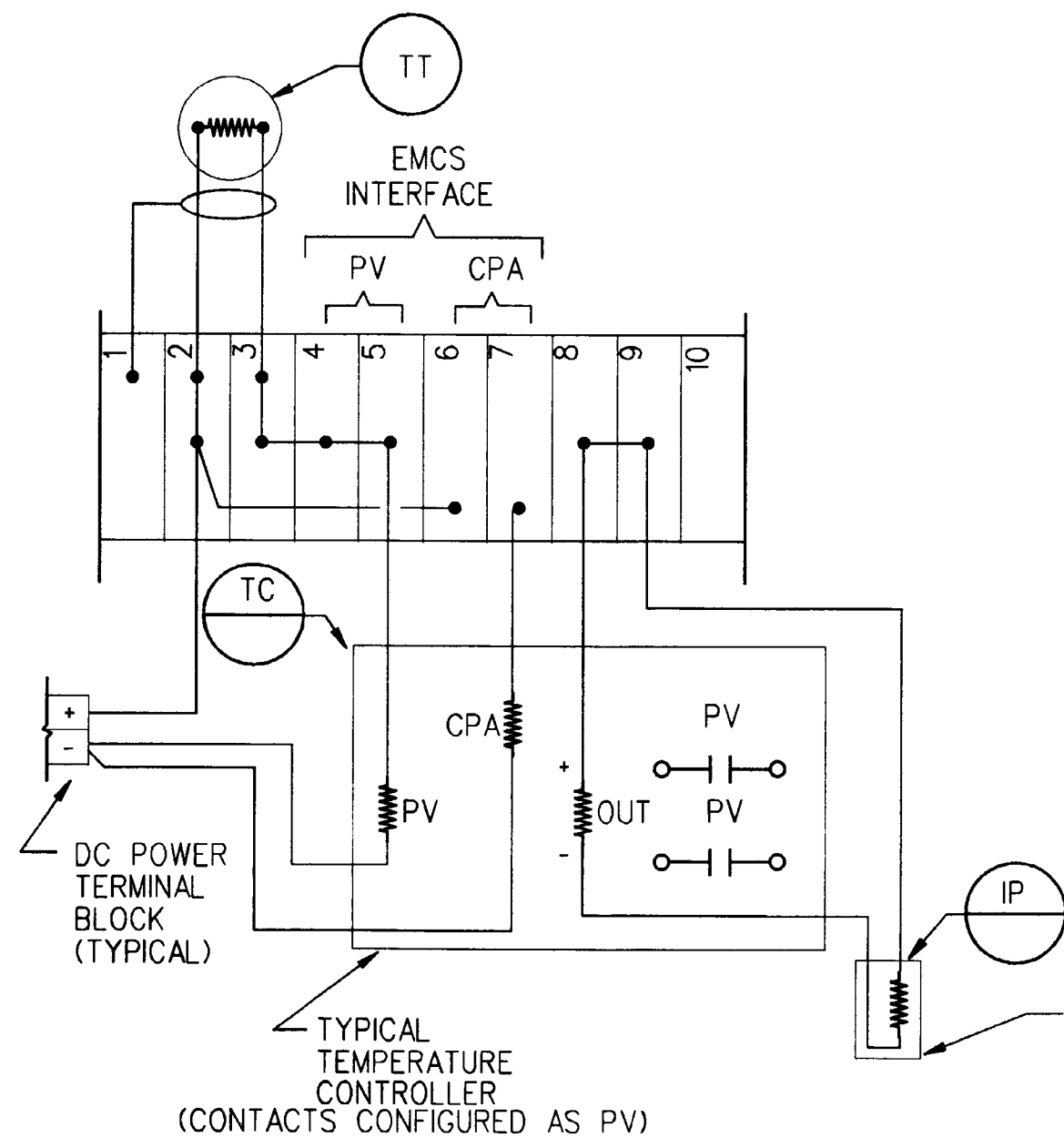
Figure 4-6D. Standard HVAC control-panel back-panel layout.

1-10 CONTROLLER	11-20 CONTROLLER	21-30 CONTROLLER	31-40 CONTROLLER	41-50 CONTROLLER	51-60 CONTROLLER	61-70 SPACE
71-80 SPACE	81-90 EMCS START/STOP INTERLOCKS	91-100 LOW-TEMP TSTAT SMOKE DET & EMCS	101-110 FILTER DPS & EMCS	111-120 DUCT STATIC- PRESSURE SWITCH	121-130 EMCS ECONOMIZER OVERRIDE	131-140 NIGHT LOW-LIMIT T-STAT & HYDRONIC SYSTEM INTERLOCK
141-170 120V AC POWER-DISTRIBUTION TERMINAL BLOCKS			171-180 24V DC POWER- DISTRIBU- TION TERMINAL BLOCKS	181-190 STARTER WIRING & END SWITCHES	191-200 STARTER WIRING & END SWITCHES	201-210 SPARE

Figure 4-6E. Standard HVAC control-panel terminal-block assignments.

1-10 CONTROLLER	11-20 CONTROLLER	21-30 CONTROLLER	31-40 CONTROLLER	41-50 CONTROLLER	51-60 CONTROLLER	61-70 SPACE
71-80 SPACE	81-90 EMCS START/STOP INTERLOCKS	91-100 LOW-TEMP TSTAT SMOKE DET & EMCS	101-110 FILTER DPS & EMCS	111-120 DUCT STATIC- PRESSURE SWITCH	121-130 EMCS ECONOMIZER OVERRIDE	131-140 NIGHT LOW-LIMIT T-STAT & HYDRONIC SYSTEM INTERLOCK
141-170 120V AC POWER-DISTRIBUTION TERMINAL BLOCKS			171-180 24V DC POWER- DISTRIBU- TION TERMINAL BLOCKS	181-190 STARTER WIRING & END SWITCHES	191-200 STARTER WIRING & END SWITCHES	201-210 SPARE

Figure 4-6E. Standard HVAC control-panel terminal-block assignments.



TYPICAL CONTROLLER WIRING
(TEMPERATURE CONTROLLER SHOWN)

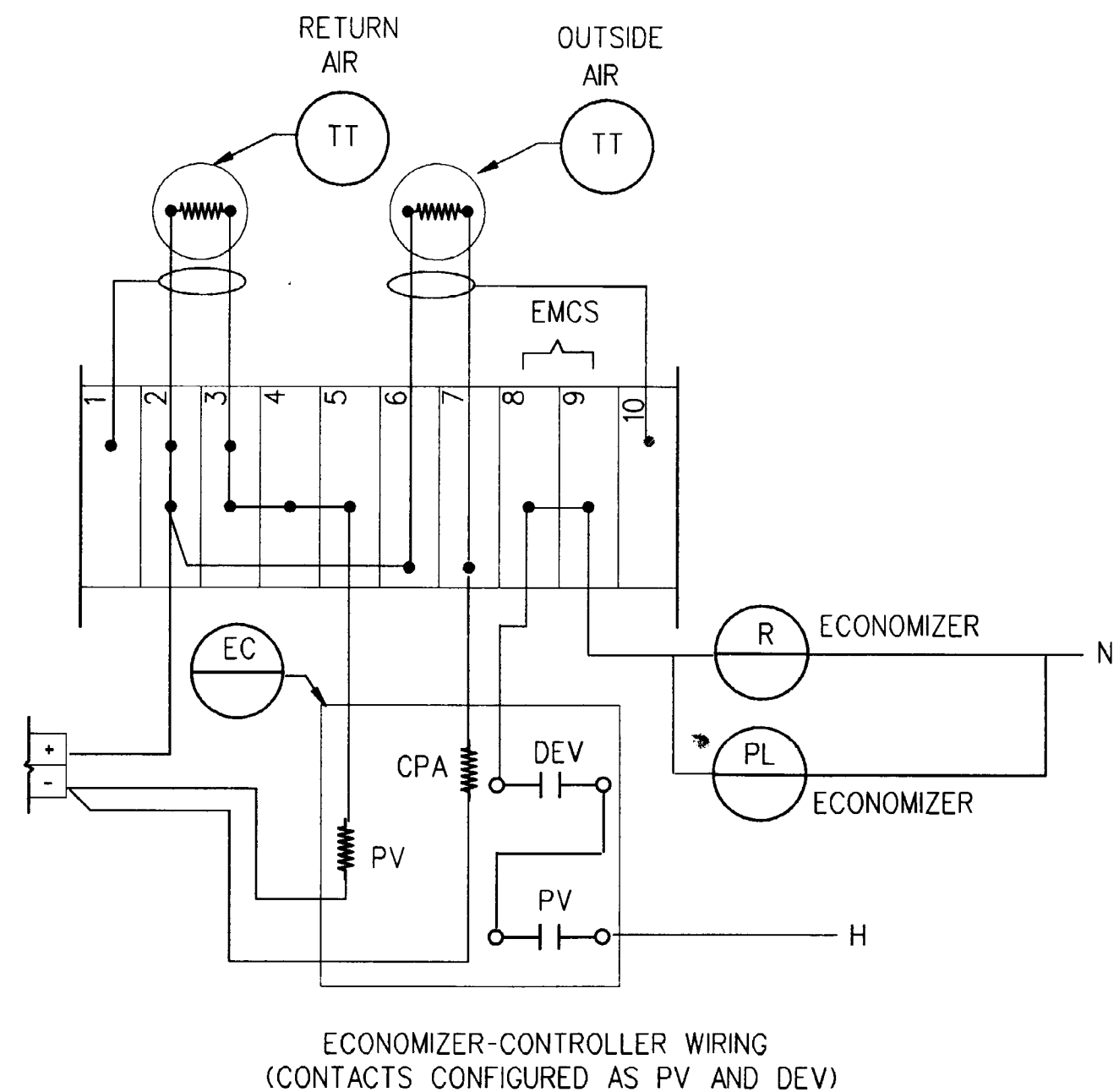


Figure 4-6F. Controller wiring.

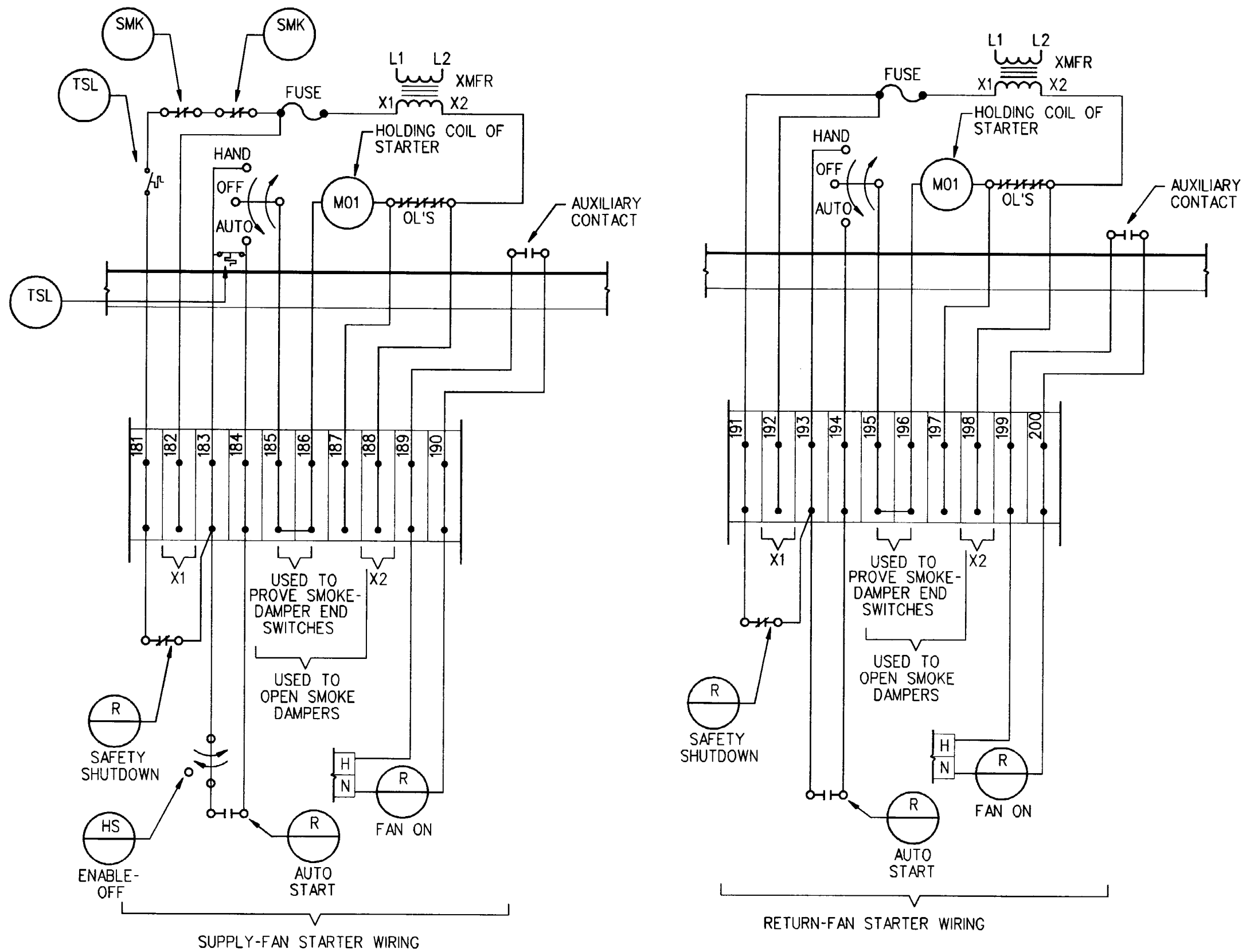


Figure 4-6G. Supply-fan and return-fan starter wiring.

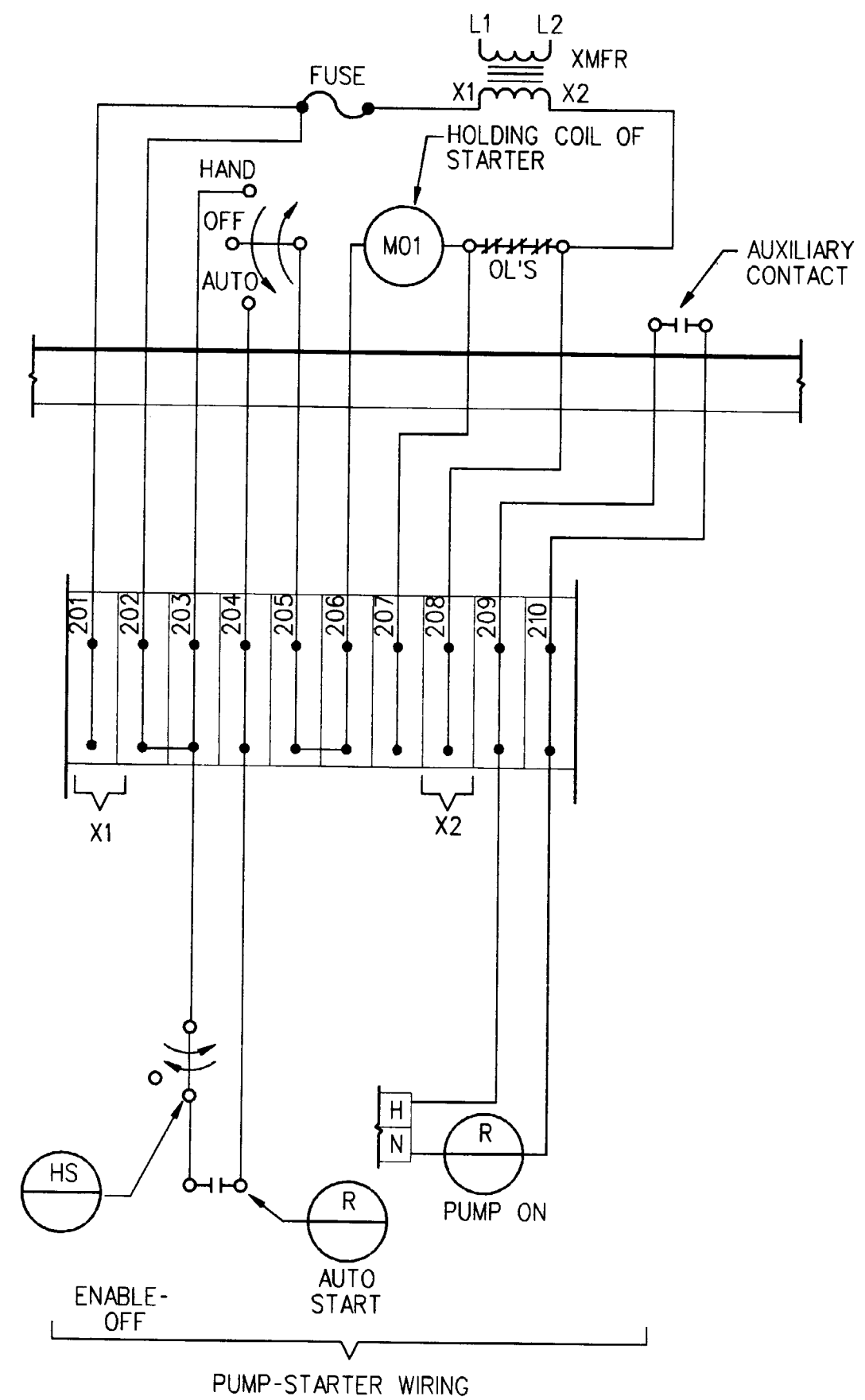
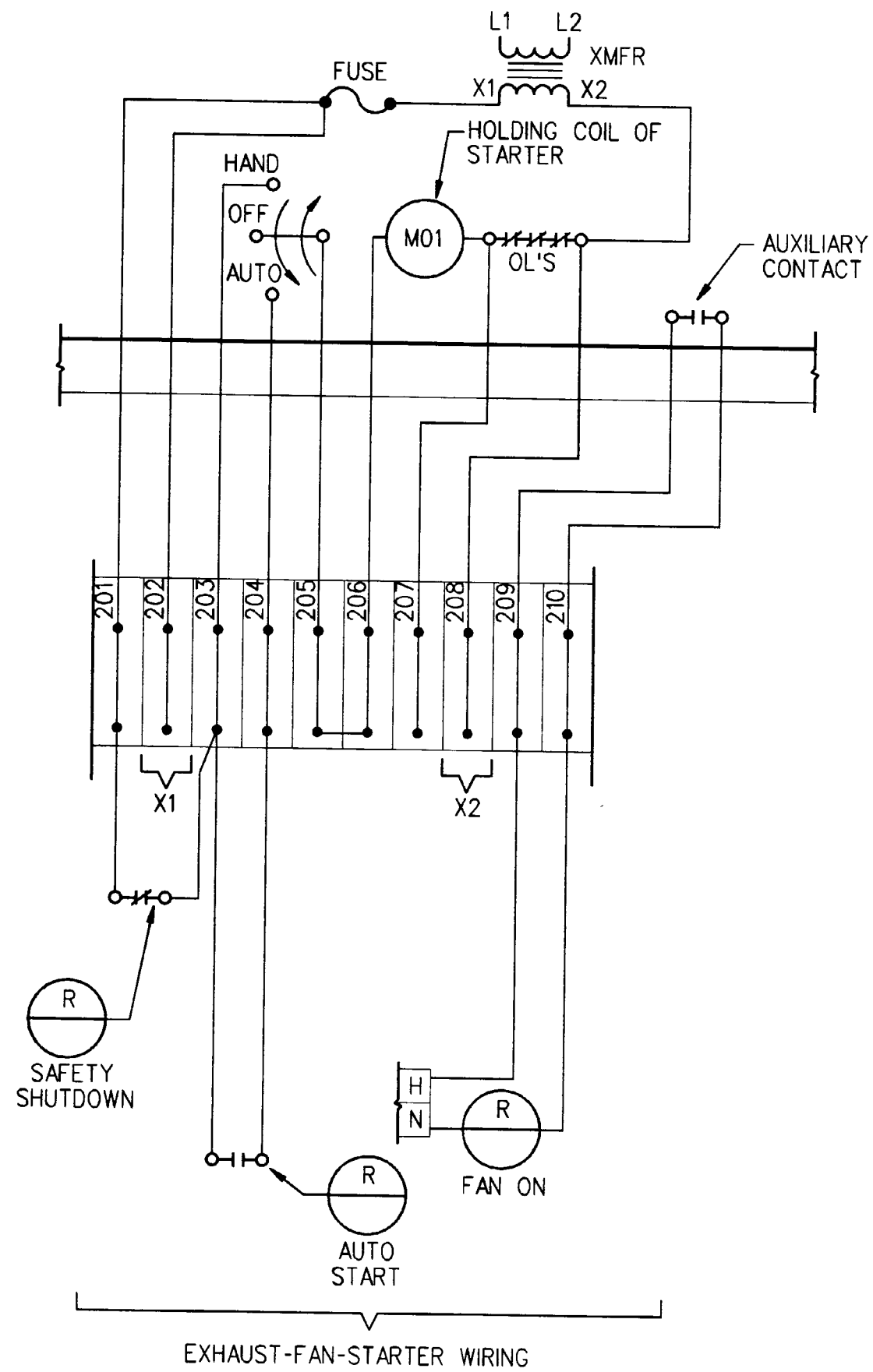


Figure 4-6H. Exhaust-fan and pump-starter wiring.

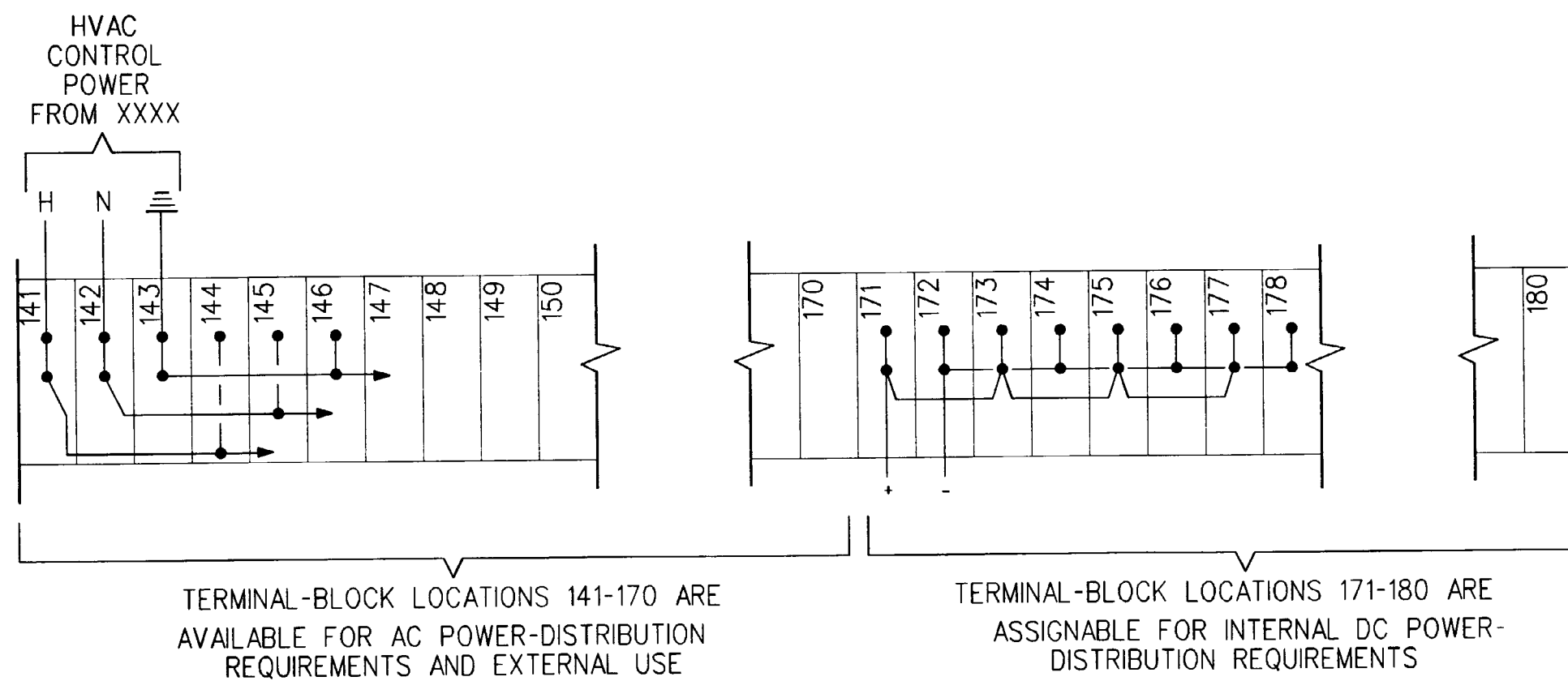


Figure 4-6I. HVAC control-panel power wiring.

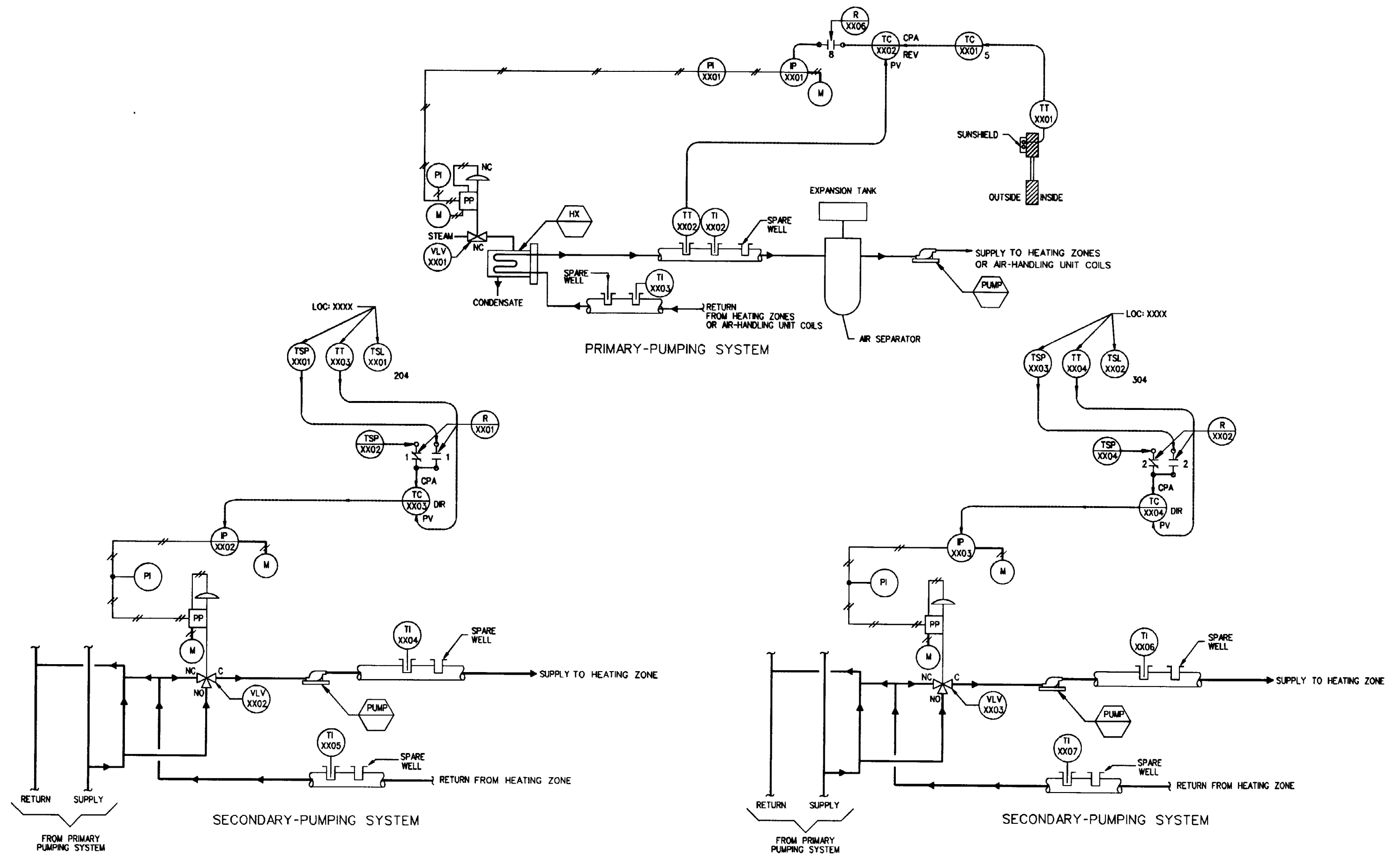


Figure 4-7A. Control-system schematic for central-plant steam hydronic-heating control system XX.

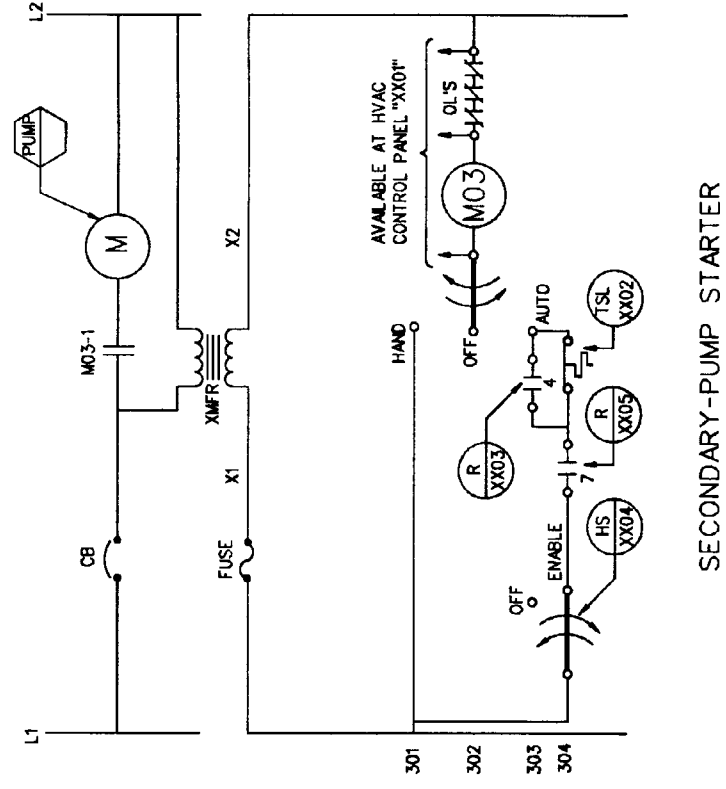
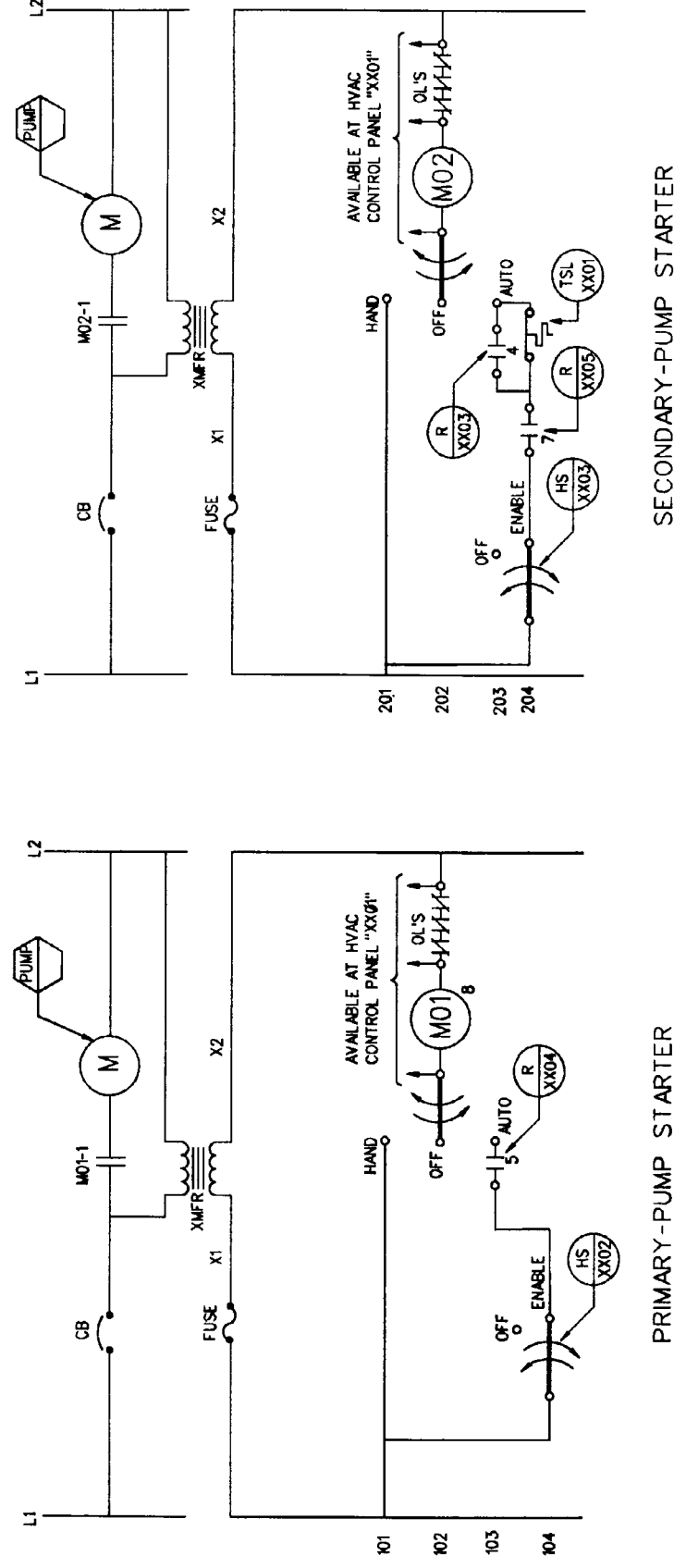
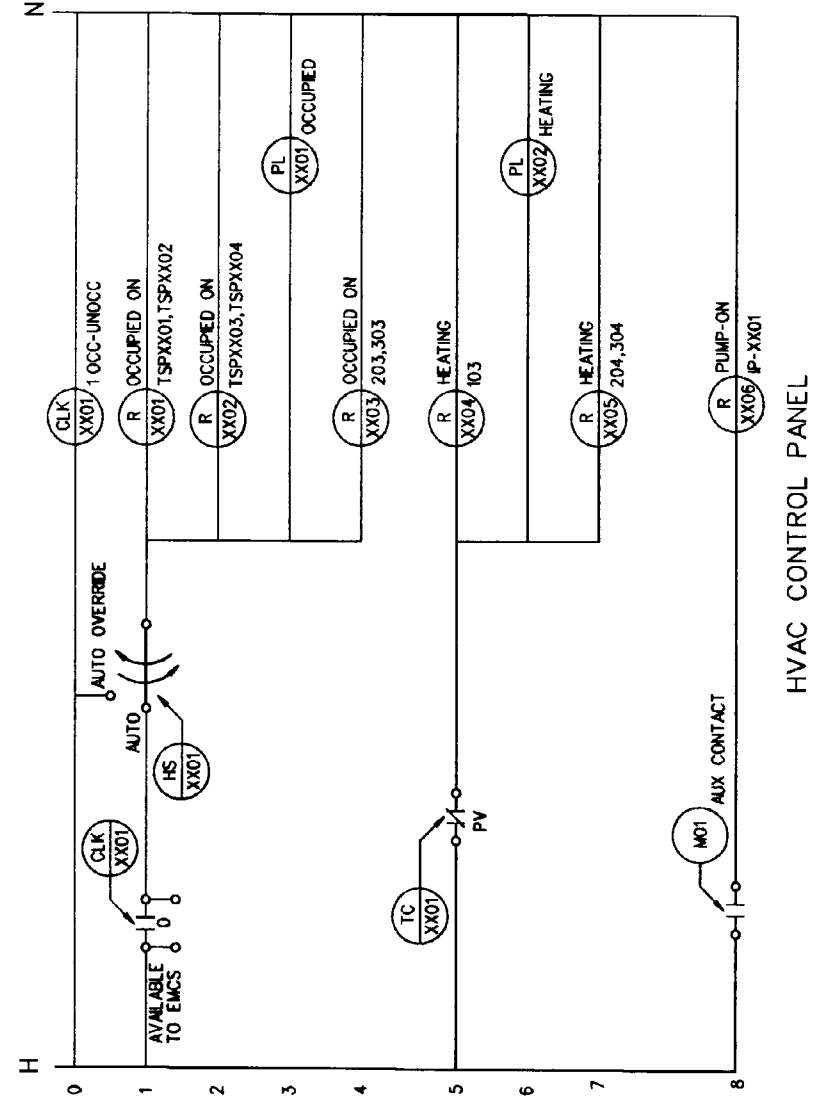
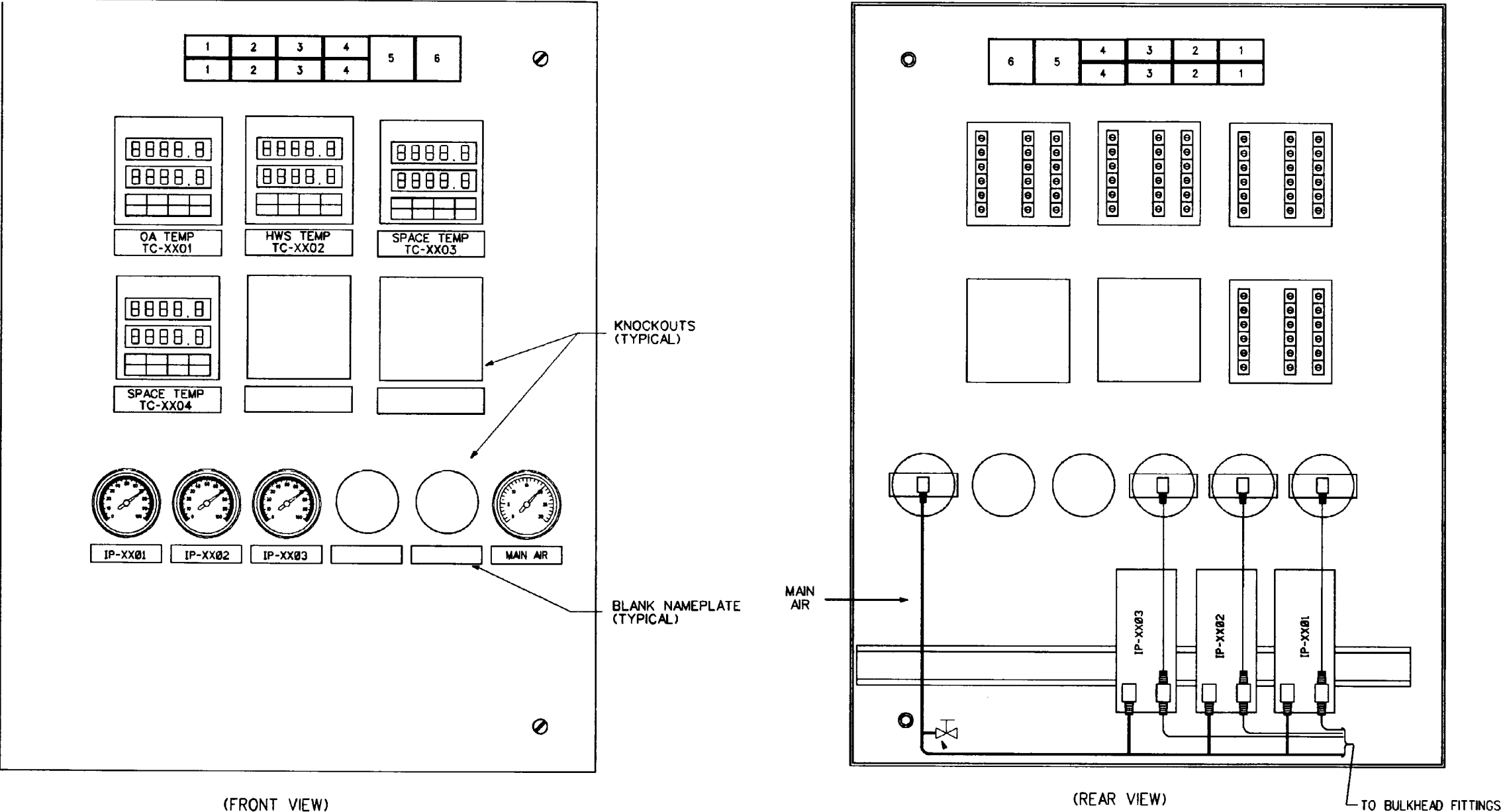


Figure 4-7B. Control-system ladder diagram for central-plant steam hydronic-heating control system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
CONVERTER TEMPERATURE	VLV-XX01	CONVERTER VALVE	—	3-15 PSIG	CV-20 CLOSE AGAINST 10 PSIG
	TC-XX01	OUTSIDE-AIR TEMPERATURE CONTROLLER	15°F PORPORTIONAL BAND 56%	-30°F TO +130°F	PV CONTACT STARTS PUMP AT 60°F STOPS PUMP AT 62°F MINIMUM OUTPUT-0% MAXIMUM OUTPUT-67%
	TC-XX02	SYSTEM-SUPPLY TEMPERATURE CONTROLLER	0A TEMP-0°F,SUPPLY TEMP-200°F 0A TEMP-60°F,SUPPLY TEMP-100°F	100 TO 250 °F	—
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30°F TO +130°F	—
	TT-XX02	SYSTEM-SUPPLY TEMPERATURE TRANSMITTER	—	100 TO 250 °F	—
SPACE TEMPERATURE	TT-XX03	SPACE-TEMPERATURE TRANSMITTER	—	50°F TO 85°F	—
	VLV-XX02	ZONE VALVE	—	3-15 PSIG	CV-7 CLOSE AGAINST 10 PSIG
	TC-XX03	SPACE- TEMPERATURE CONTROLLER	4 MA-50°F 20 MA-85°F	50°F TO 85°F	SET LIMITS AVAILABLE TO OCCUPANT BY TSP-XX01 AT 66 TO 72°F
	TSP-XX01	MANUAL-SETPOINT ADJUSTMENT	4 MA - 50 °F 20 MA - 85 °F	—	AVAILABLE TO OCCUPANT
	TSP-XX02	MANUAL-SETPOINT ADJUSTMENT	57 °F	—	—
SPACE LOW- LIMIT TEMPERATURE	TSL-XX01	LOW-LIMIT SPACE- TEMPERATURE THERMOSTAT	55°F	—	STARTS PUMP AT 55°F STOPS PUMP AT 57°F
SPACE TEMPERATURE	TT-XX04	SPACE-TEMPERATURE TRANSMITTER	—	50°F TO 85°F	—
	VLV-XX03	ZONE VALVE	—	3-15 PSIG	CV-7 CLOSE AGAINST 10 PSIG
	TC-XX04	SPACE- TEMPERATURE CONTROLLER	4 MA-50°F 20 MA-85°F	50°F TO 85°F	SET LIMITS AVAILABLE TO OCCUPANT BY TSP-XX03 AT 66 TO 72°F
	TSP-XX03	MANUAL-SETPOINT ADJUSTMENT	4 MA - 50 °F 20 MA - 85 °F	—	AVAILABLE TO OCCUPANT
	TSP-XX04	MANUAL-SETPOINT ADJUSTMENT	57 °F	—	—
SPACE LOW- LIMIT TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE- TEMPERATURE THERMOSTAT	55°F	—	STARTS PUMP AT 55°F STOPS PUMP AT 57°F
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS. OPEN: 1700 HRS M,T,W,TH,F	OPEN: SAT. SUN AND HOLIDAYS

NOTE : OTHER CONTROL DEVICES SUCH AS IPS AND RELAYS ARE NOT SHOWN

Figure 4-7C. Equipment for central-plant steam hydronic-heating control system XX.



SWITCH AND PILOT-LIGHT LEGEND		
POSITION LEGEND	DEVICE TYPE	IDENTIFIER
1 - AUTO/AUTO OVERRIDE	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX01
2 - ENABLE/OFF	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX02
3 - ENABLE/OFF	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX03
4 - ENABLE/OFF	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX04
5 - OCC	PILOT LIGHT	PL-XX01
6 - HEATING	PILOT LIGHT	PL-XX02

Figure 4-7D. Control-panel interior-door layout for central-plant steam hydronic-heating control system XX.

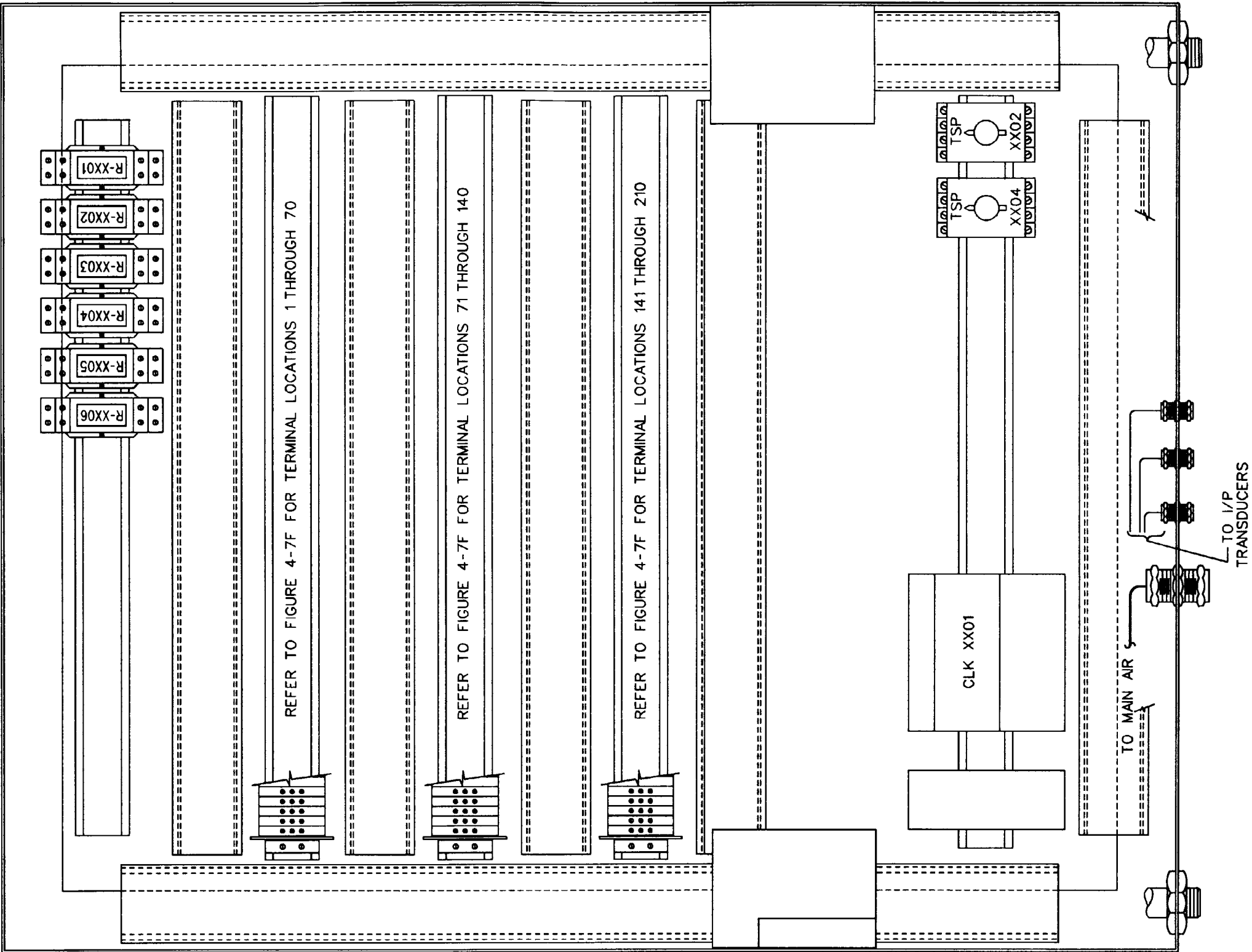


Figure 4-7E. Back-panel layout for central-plant steam hydronic-heating control system XX control panel.

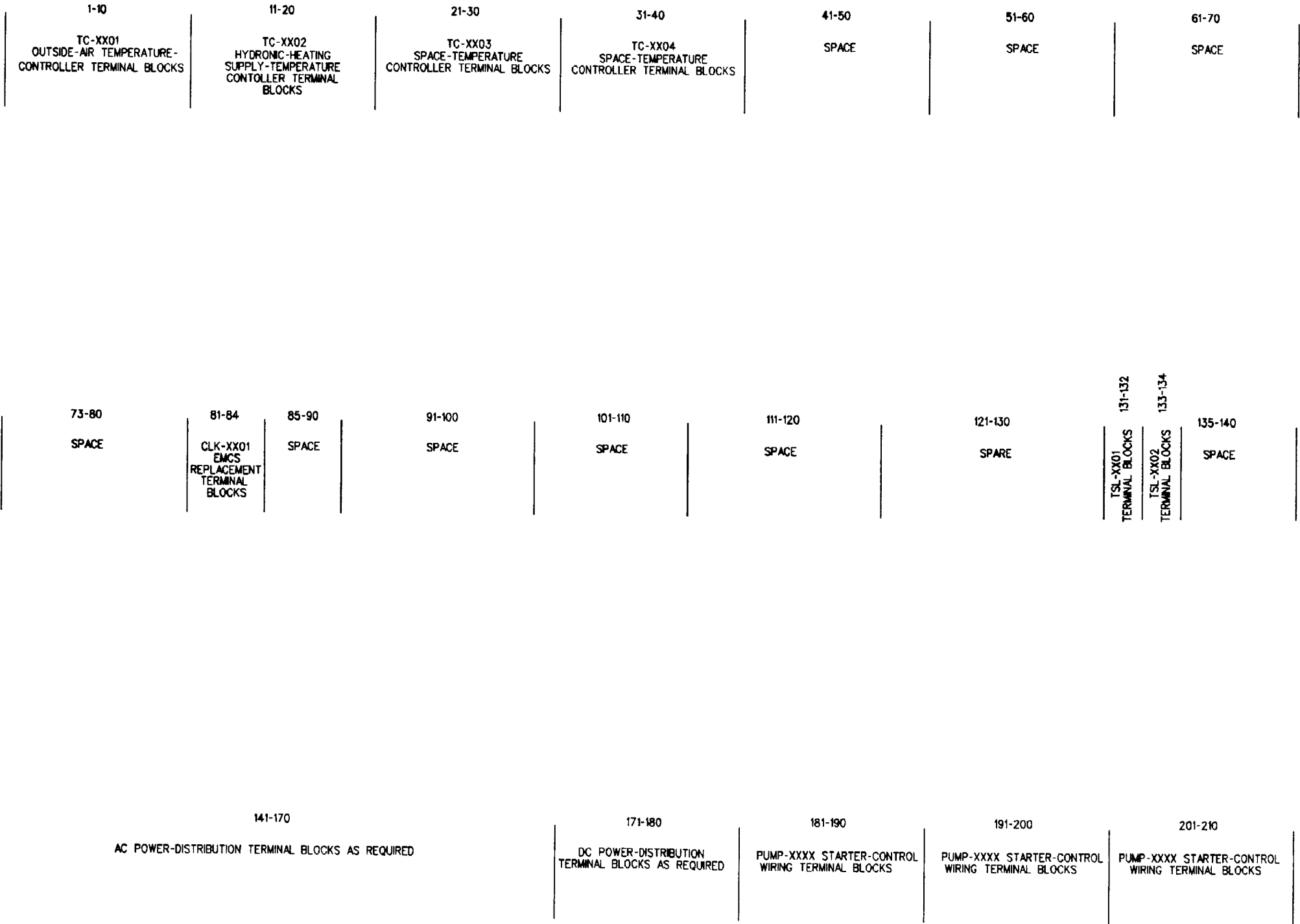


Figure 4-7F. Terminal-block layout for central-plant steam hydronic-heating control system XX control panel.

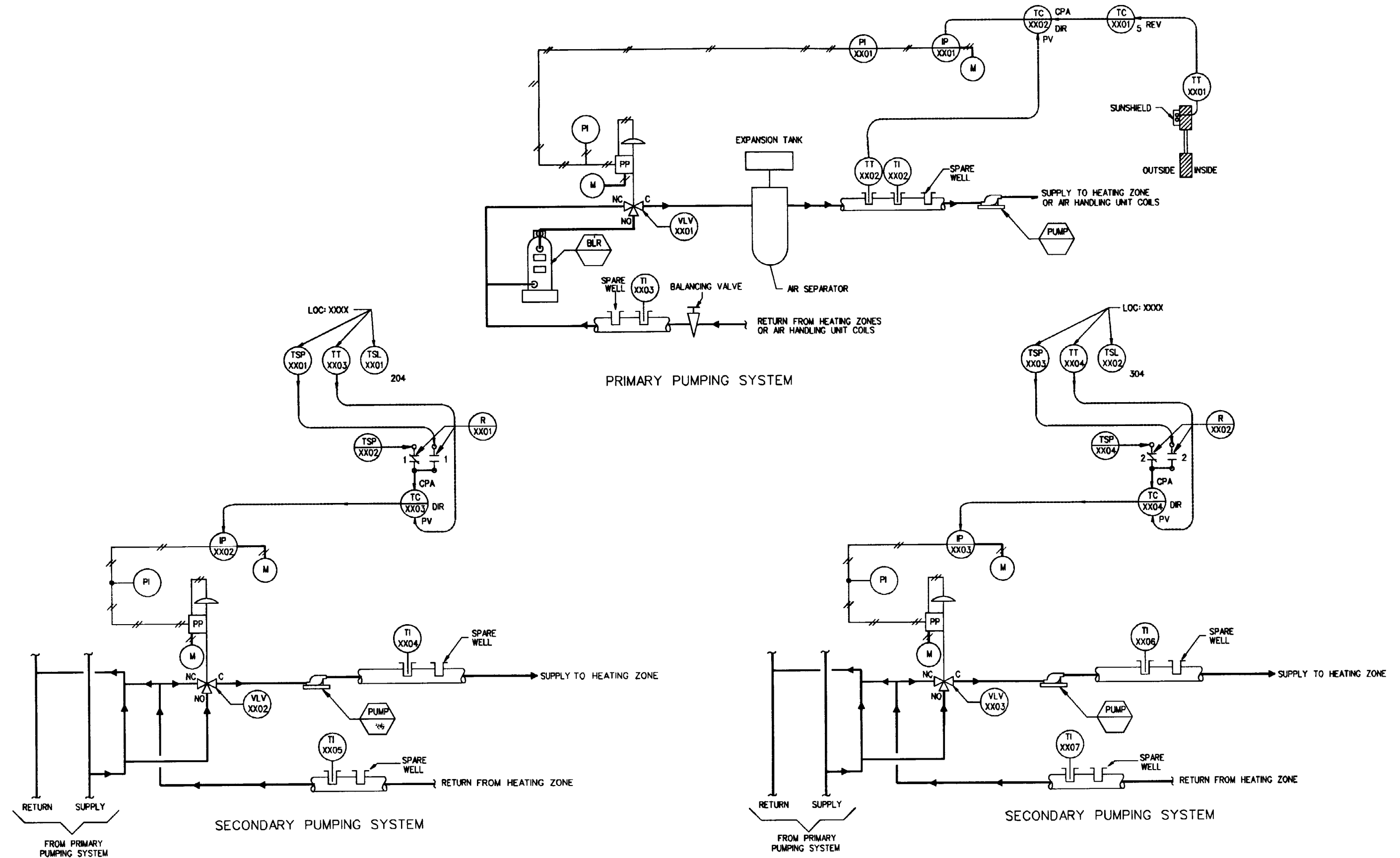
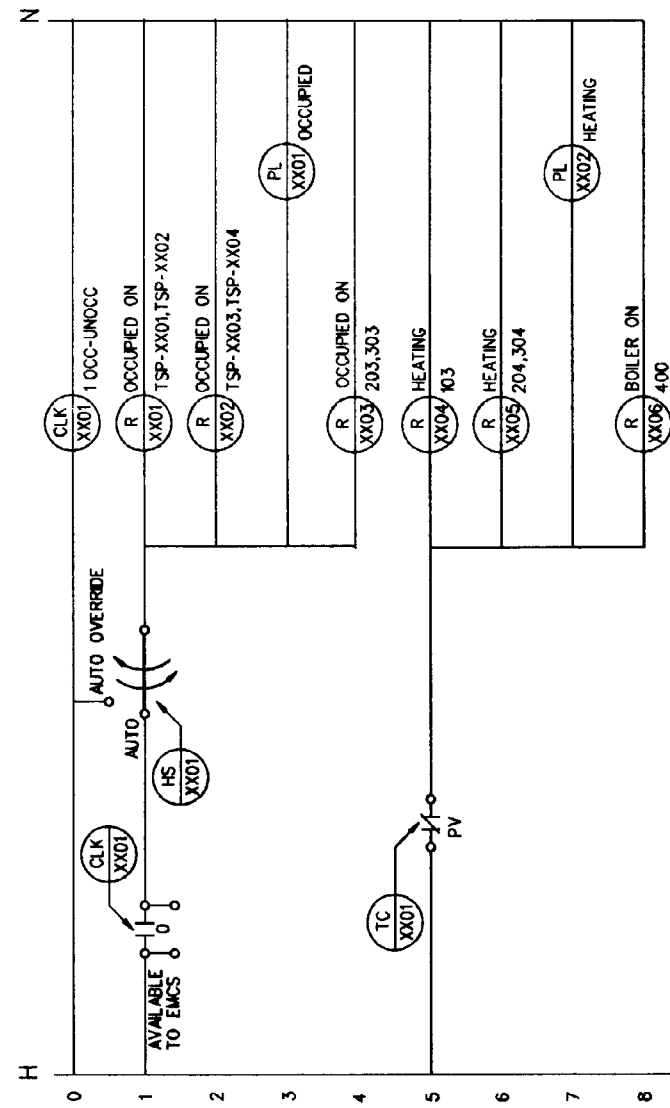
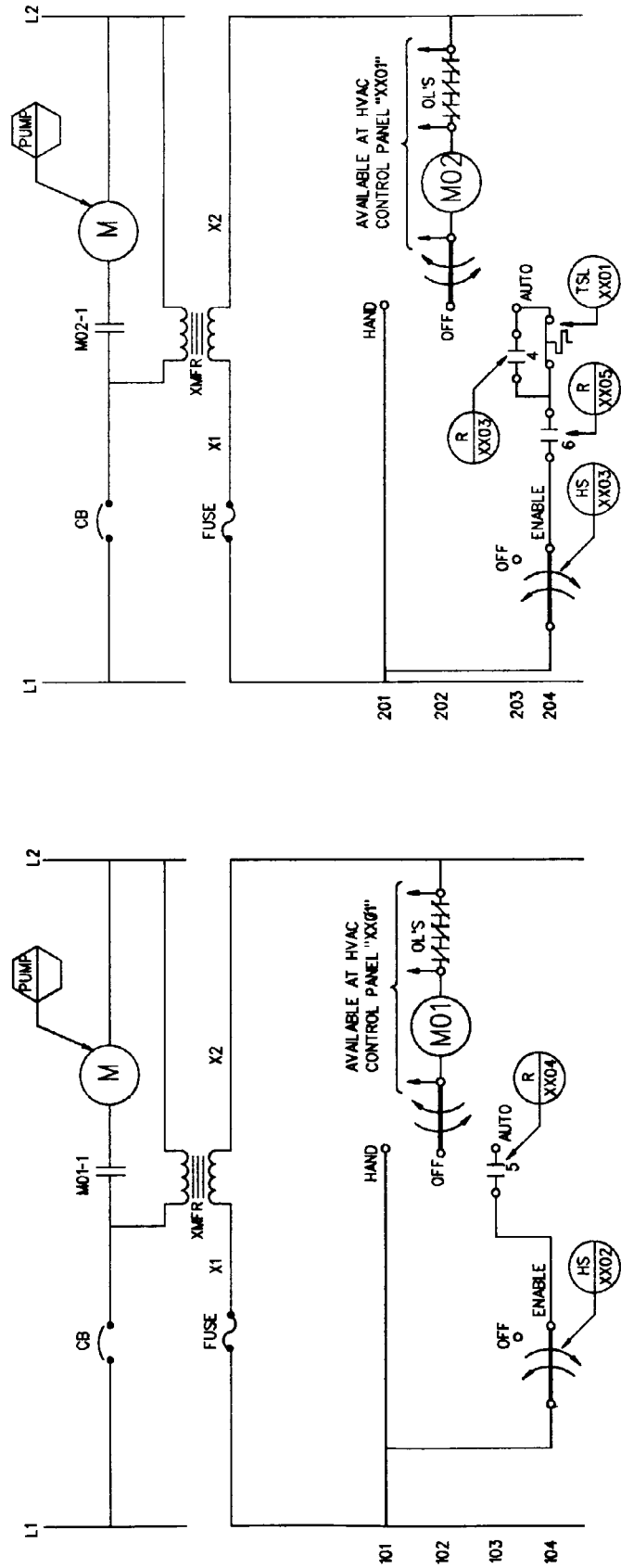


Figure 4-8A. Control-system schematic for single-building hydronic-heating with hot water boiler control system XX.

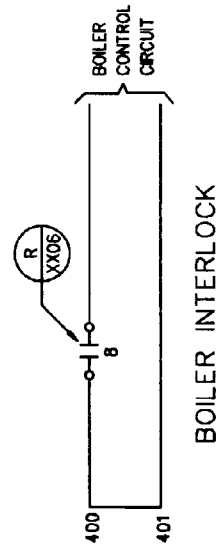


HVAC CONTROL PANEL

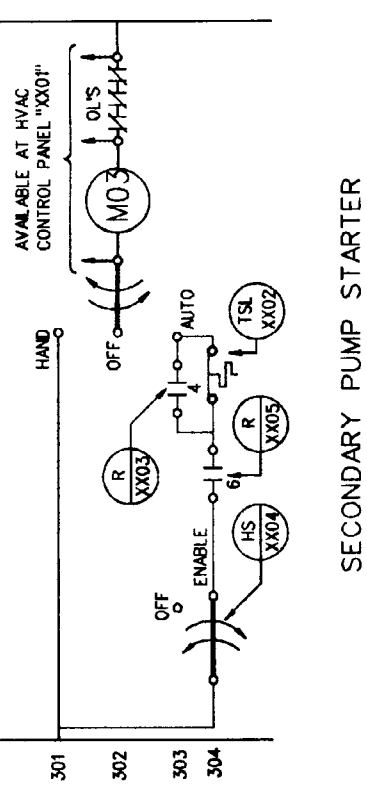


PRIMARY PUMP STARTER

SECONDARY PUMP STARTER



BOILER INTERLOCK



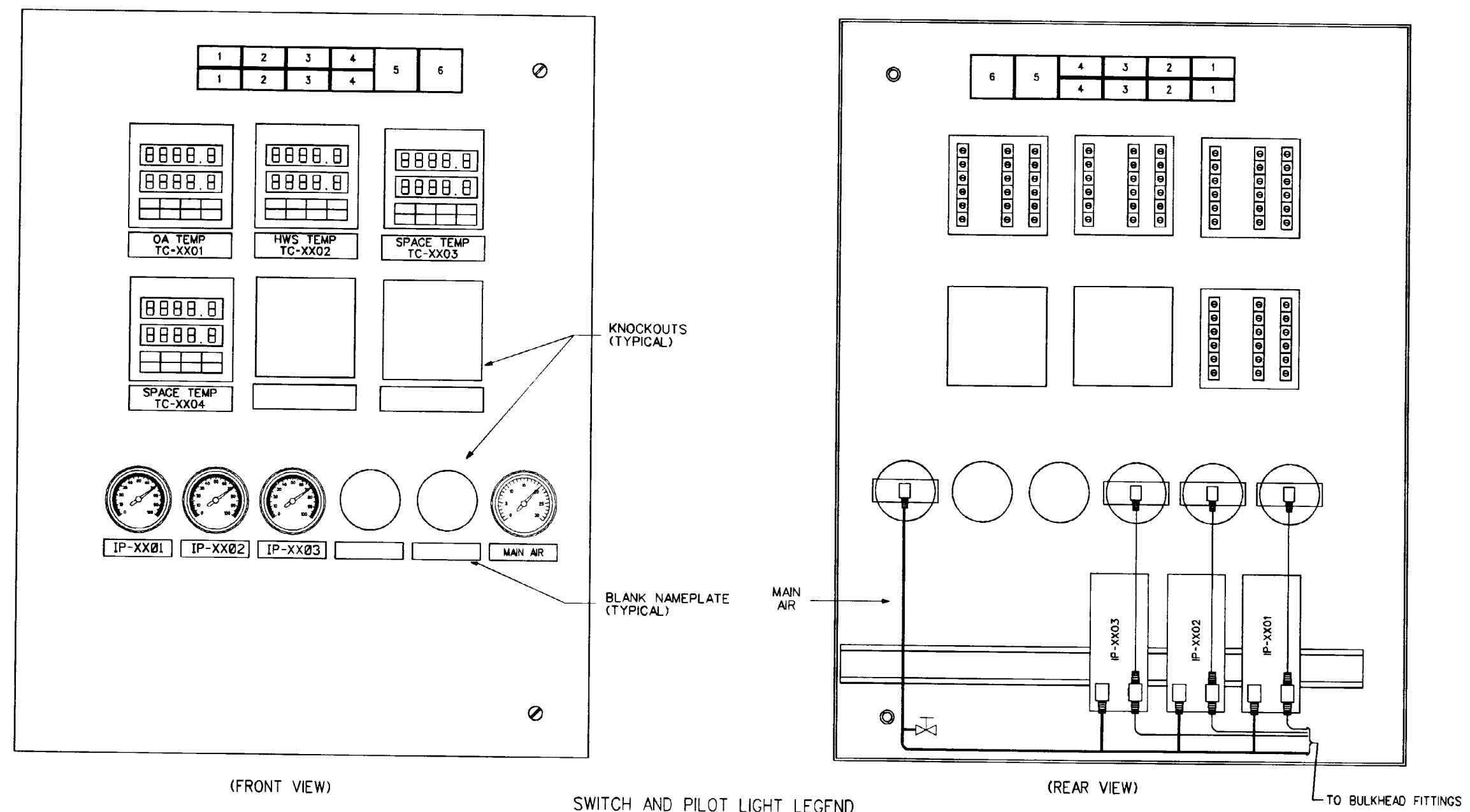
SECONDARY PUMP STARTER

Figure 4-8B. Control-system ladder diagram for single-building hydronic-heating with hot water boiler control system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
HYDRONIC-HEATING SUPPLY TEMPERATURE	VLV-XX01	SYSTEM VALVE	—	3-15 PSIG	CV-19 CLOSE AGAINST 10 PSIG
	TC-XX01	OUTSIDE-AIR TEMPERATURE CONTROLLER	15°F PROPORTIONAL BAND 56%	-30°F TO +130°F	PV CONTACT STARTS PUMP AT 60°F STOPS PUMP AT 62°F MINIMUM OUTPUT-0% MAXIMUM OUTPUT-67%
	TC-XX02	SYSTEM-SUPPLY TEMPERATURE CONTROLLER	0A TEMP-0°F,SUPPLY TEMP-200°F 0A TEMP-60°F,SUPPLY TEMP-100°F	100 TO 250°F	—
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30°F TO +130°F	—
	TT-XX02	SYSTEM-SUPPLY TEMPERATURE TRANSMITTER	—	100 TO 250°F	—
SPACE TEMPERATURE	TT-XX03	SPACE TEMPERATURE TRANSMITTER	—	50°F TO 85°F	—
	VLV-XX02	ZONE VALVE	—	3-15 PSIG	CV-7 CLOSE AGAINST 10 PSIG
	TC-XX03	SPACE- TEMPERATURE CONTROLLER	4 MA-50°F 20 MA-85°F	50°F TO 85°F	SET LIMITS AVAILABLE TO OCCUPANT BY TSP-XX01 AT 66° TO 72°F
	TSP-XX01	MANUAL SETPOINT ADJUSTMENT	4 MA - 55°F 20 MA - 85°F	—	AVAILABLE TO OCCUPANT
	TSP-XX02	MANUAL SETPOINT ADJUSTMENT	57°F	—	—
SPACE LOW- LIMIT TEMPERATURE	TSL-XX01	LOW-LIMIT SPACE TEMPERATURE THERMOSTAT	55°F	—	STARTS PUMP AT 55°F STOPS PUMP AT 57°F
SPACE TEMPERATURE	TT-XX04	SPACE-TEMPERATURE TRANSMITTER	—	50°F TO 85°F	—
	VLV-XX03	ZONE VALVE	—	3-15 PSIG	CV-7 CLOSE AGAINST 10 PSIG
	TC-XX04	SPACE- TEMPERATURE CONTROLLER	4 MA-50°F 20 MA-85°F	55°F TO 85°F	SET LIMITS AVAILABLE TO OCCUPANT BY TSP-XX03 AT 66° TO 72°F
	TSP-XX03	MANUAL SETPOINT ADJUSTMENT	4 MA - 55°F 20 MA - 85°F	—	AVAILABLE TO OCCUPANT
	TSP-XX04	MANUAL SETPOINT ADJUSTMENT	57°F	—	—
SPACE LOW- LIMIT TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE TEMPERATURE THERMOSTAT	55°F	—	STARTS PUMP AT 55°F STOPS PUMP AT 57°F
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 1700 HRS M,T,W,TH,F	OPEN: SAT, SUN AND HOLIDAYS

NOTE: OTHER CONTROL DEVICES SUCH AS IPS AND RELAYS ARE NOT SHOWN

Figure 4-8C. Equipment for single-building hydronic-heating with hot water boiler control system XX.



POSITION LEGEND	DEVICE TYPE	IDENTIFIER
1 - AUTO/AUTO OVERRIDE	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX01
2 - ENABLE/OFF	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX02
3 - ENABLE/OFF	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX03
4 - ENABLE/OFF	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX04
5 - OCC	PILOT LIGHT	PL-XX01
6 - HEATING	PILOT LIGHT	PL-XX02

Figure 4-8D. Control-panel interior-door layout for single-building hydronic-heating with hot water boiler control system XX.

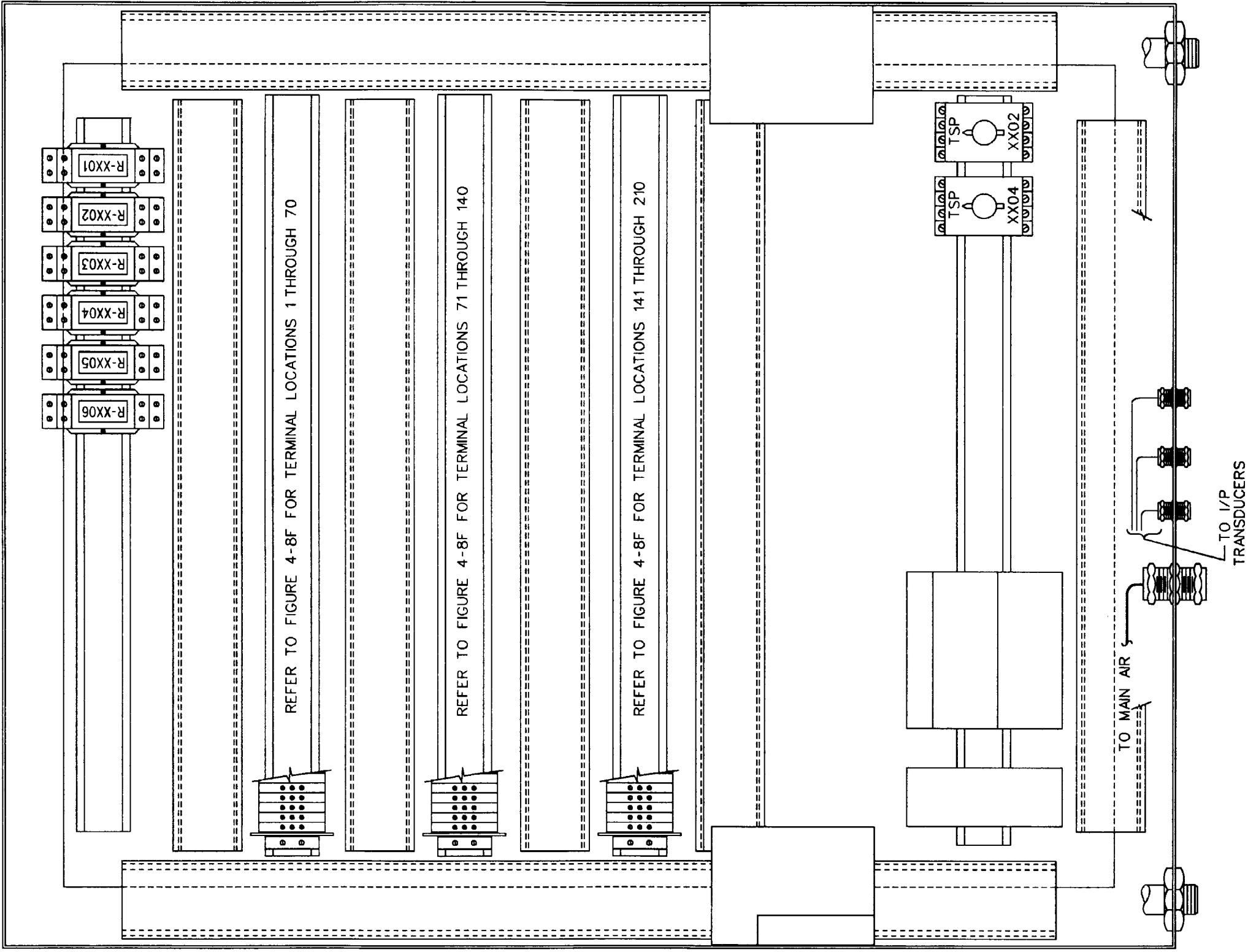


Figure 4-8E. Back-panel layout for single-building hydronic-heating with hot water boiler control system XX control panel.

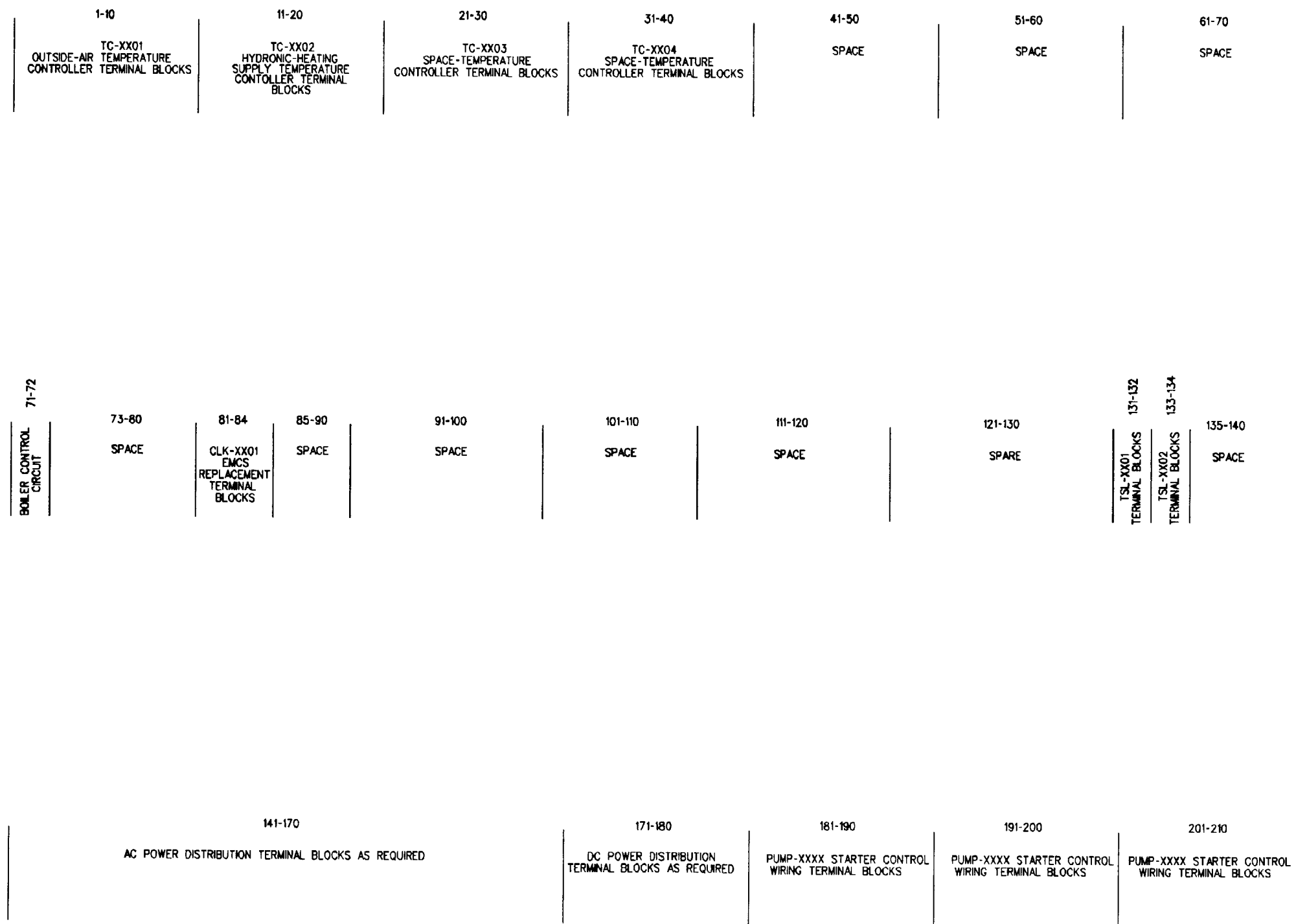


Figure 4-8F. Terminal-block layout for single-building hydronic-heating with hot water boiler control system XX control panel.

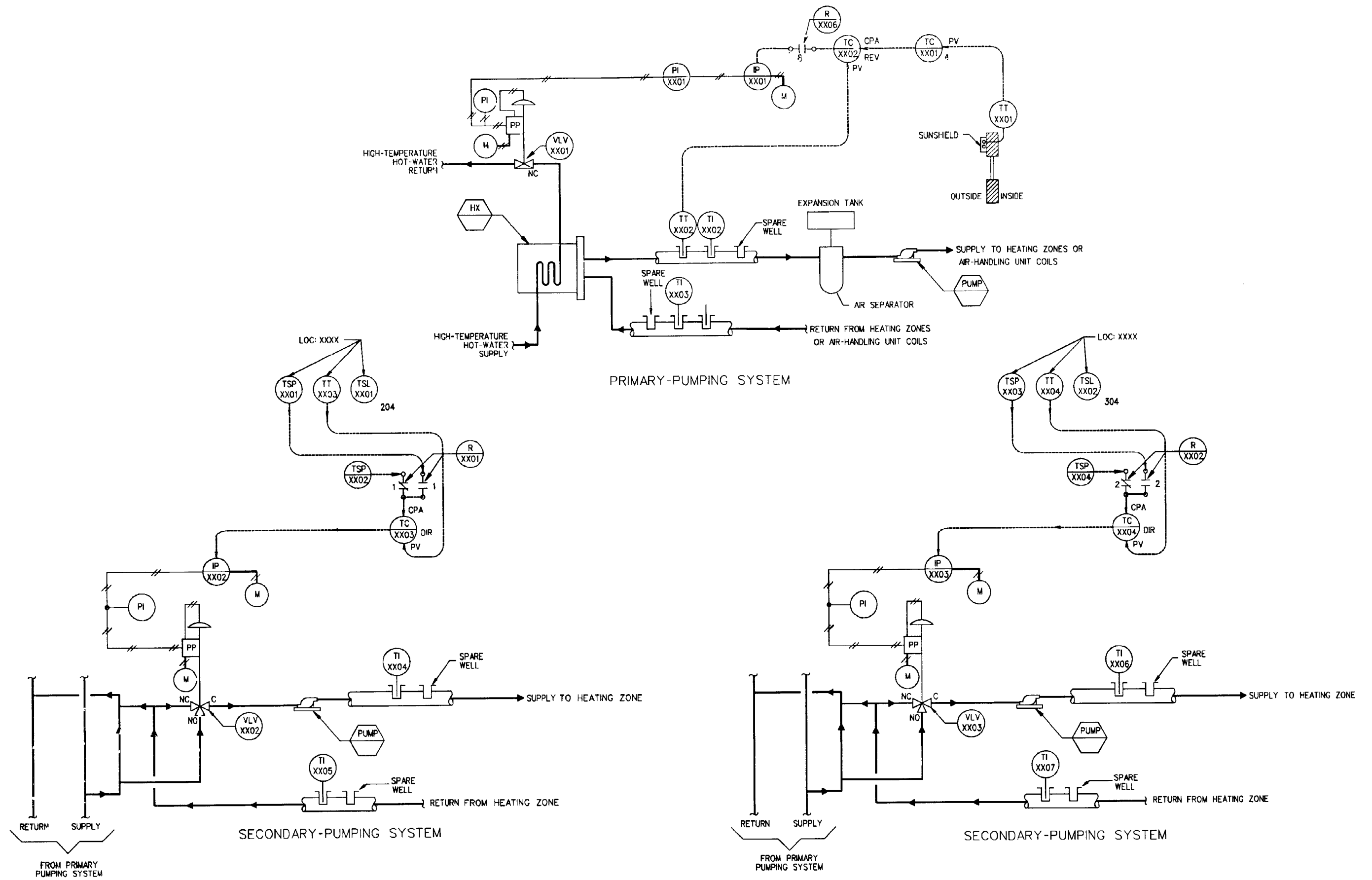
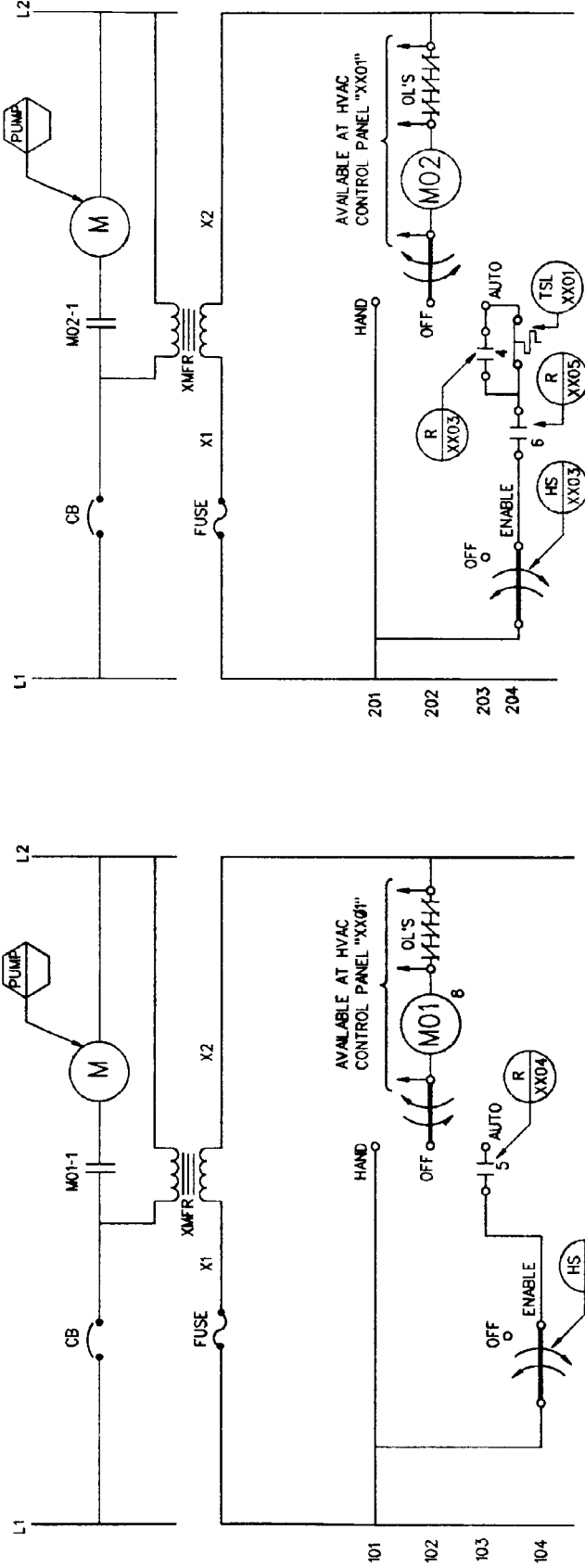
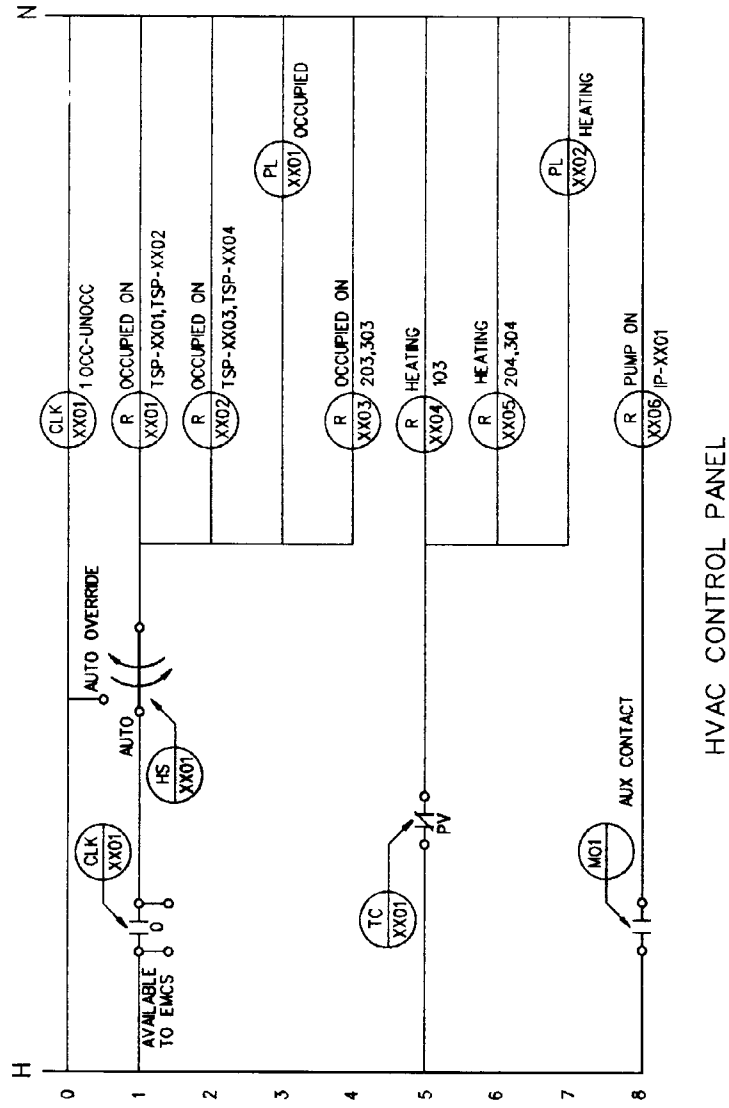
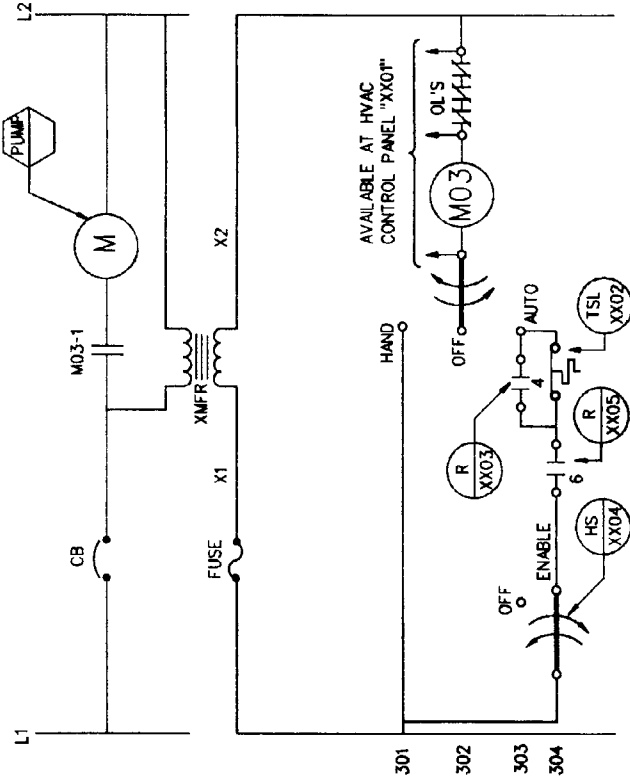


Figure 4-9A. Control-system schematic for central-plant high-temperature hot-water hydronic-heating control system XX.



PRIMARY-PUMP STARTER



SECONDARY-PUMP STARTER

Figure 4-9B. Control-system ladder diagram for central-plant high-temperature hot-water hydronic-heating control system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
CONVERTOR TEMPERATURE	VLV-XX01	CONVERTOR CONTROL VALVE	—	3-15 PSIG	CV-20 CLOSE AGAINST 120 PSIG
	TC-XX01	OUTSIDE-AIR TEMPERATURE CONTROLLER	15°F PORPORTIONAL BAND-56%	-30° TO +130 °F	PV CONTACT STARTS PUMP AT 60°F STOPS PUMP AT 62°F MINIMUM OUTPUT-0% MAXIMUM OUTPUT-67%
	TC-XX02	SYSTEM-SUPPLY TEMPERATURE CONTROLLER	0A TEMP-0°F,SUPPLY TEMP-200°F 0A TEMP-60°F,SUPPLY TEMP-100°F	100 TO 250 °F	—
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30° TO +130°F	—
	TT-XX02	SYSTEM-SUPPLY TEMPERATURE TRANSMITTER	—	100 TO 250 °F	—
SPACE TEMPERATURE	TT-XX03	SPACE-TEMPERATURE TRANSMITTER	—	50°F TO 85°F	—
	VLV-XX02	ZONE VALVE	—	3-15 PSIG	CV-7 CLOSE AGAINST 10 PSIG
	TC-XX03	SPACE- TEMPERATURE CONTROLLER	4 MA-50°F 20 MA-85°F	50°F TO 85°F	SET LIMITS AVAILABLE TO OCCUPANT BY TSP-XX01 AT 66 TO 72°F
	TSP-XX01	MANUAL-SETPOINT ADJUSTMENT	4 MA - 50 °F 20 MA - 85 °F	—	AVAILABLE TO OCCUPANT
	TSP-XX02	MANUAL-SETPOINT ADJUSTMENT	57°F	—	—
SPACE LOW- LIMIT TEMPERATURE	TSL-XX01	LOW-LIMIT SPACE- TEMPERATURE THERMOSTAT	55°F	—	STARTS PUMP AT 55°F STOPS PUMP AT 57°F
SPACE TEMPERATURE	TT-XX04	SPACE-TEMPERATURE TRANSMITTER	—	50°F TO 85°F	—
	VLV-XX03	ZONE VALVE	—	3-15 PSIG	CV-7 CLOSE AGAINST 10 PSIG
	TC-XX04	SPACE- TEMPERATURE CONTROLLER	4 MA-50°F 20 MA-85°F	50°F TO 85°F	SET LIMITS AVAILABLE TO OCCUPANT BY TSP-XX03 AT 66 TO 72°F
	TSP-XX03	MANUAL-SETPOINT ADJUSTMENT	4 MA - 50 °F 20 MA - 85 °F	—	AVAILABLE TO OCCUPANT
	TSP-XX04	MANUAL-SETPOINT ADJUSTMENT	57°F	—	—
SPACE LOW- LIMIT TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE- TEMPERATURE THERMOSTAT	55°F	—	STARTS PUMP AT 55°F STOPS PUMP AT 57°F
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS. OPEN: 1700 HRS M,T,W,Th,F	OPEN: SAT, SUN AND HOLIDAYS

NOTE:OTHER DEVICES SUCH AS IPS AND RELAYS ARE NOT SHOWN

Figure 4-9C. Equipment for central-plant high-temperature hot-water hydronic-heating control system XX.

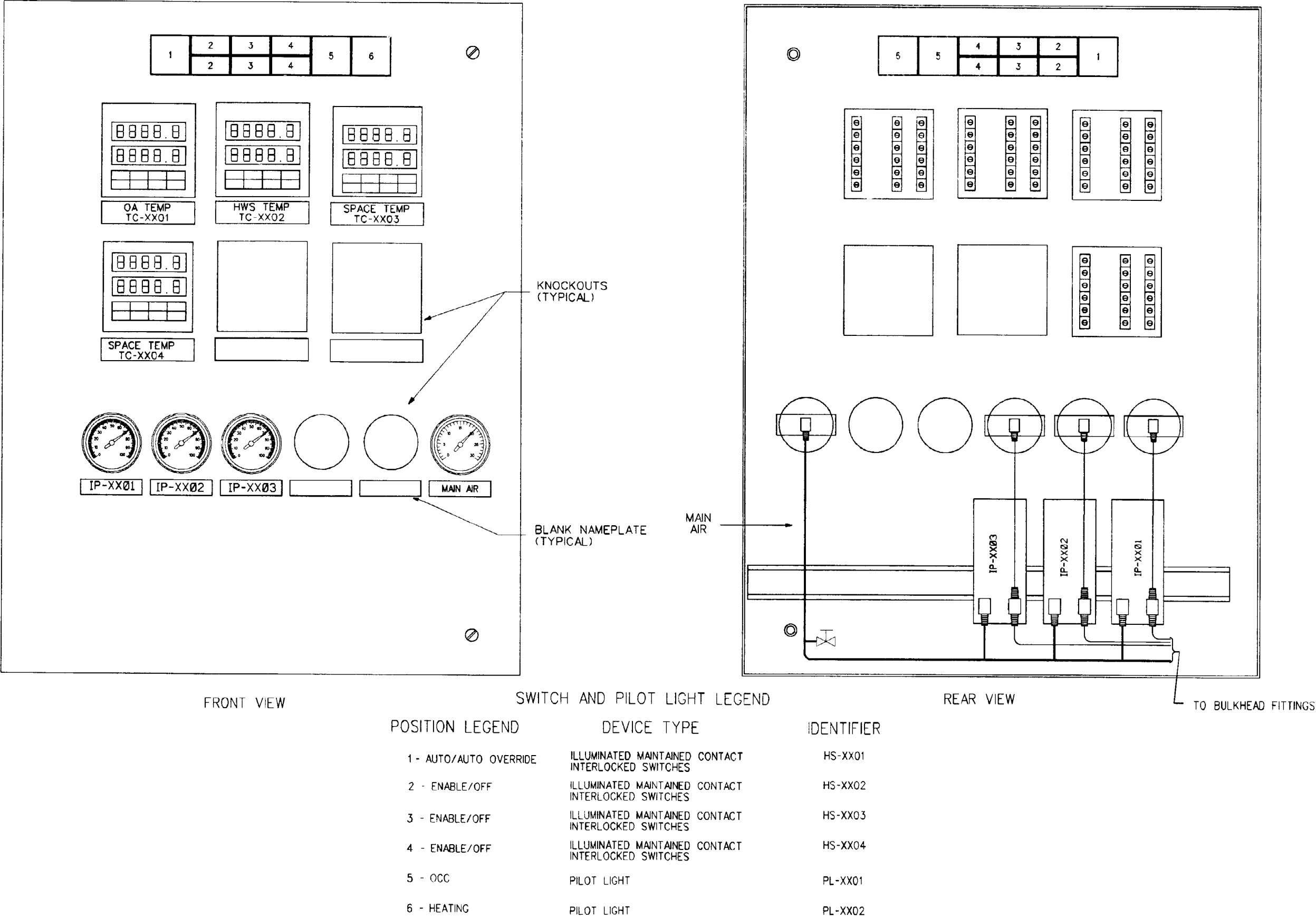


Figure 4-9D. Control-panel interior-door layout for central-plant high-temperature hot-water hydronic-heating control system XX.

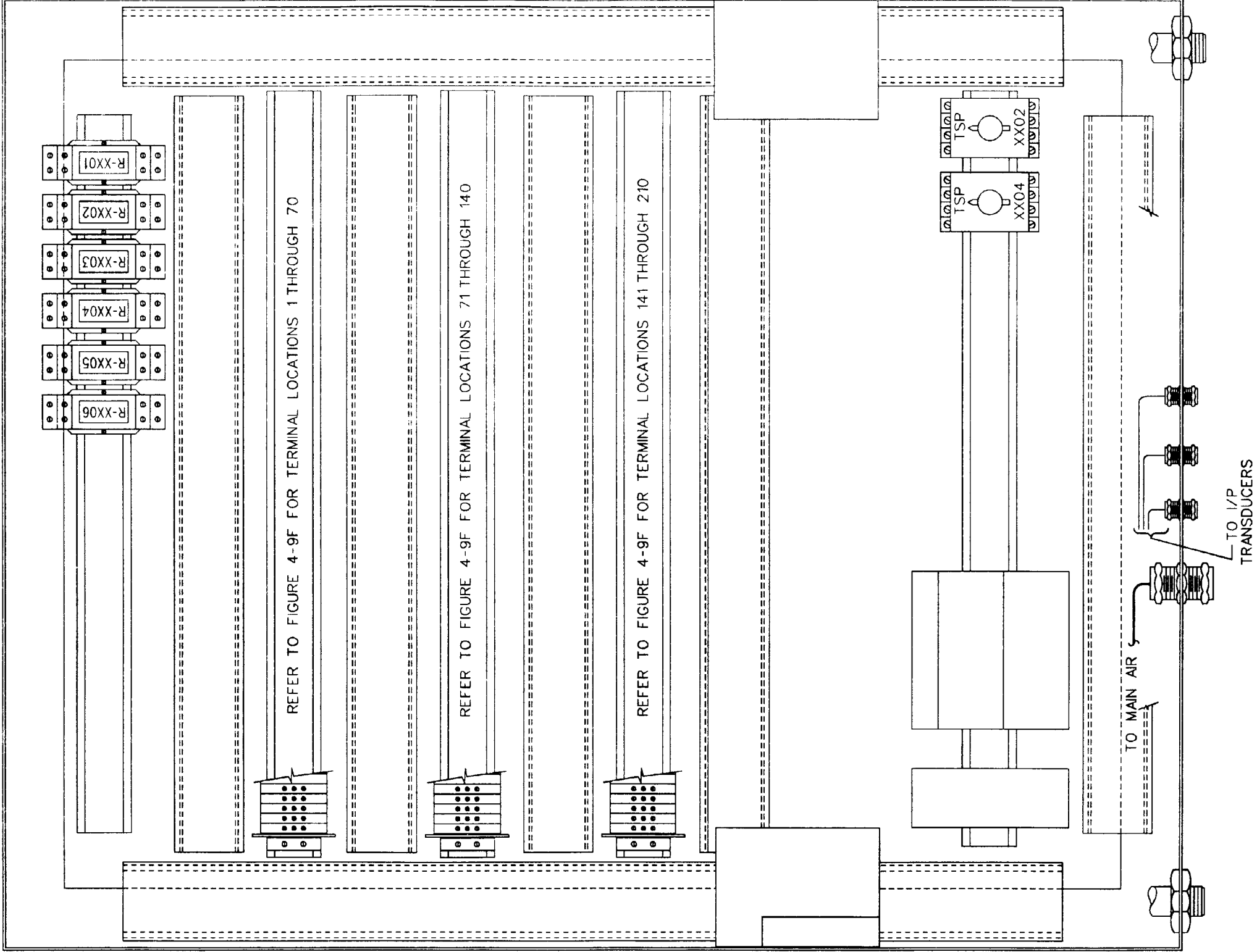


Figure 4-9E. Back-panel layout for central-plant high-temperature hot-water hydronic-heating system XX Control panel.

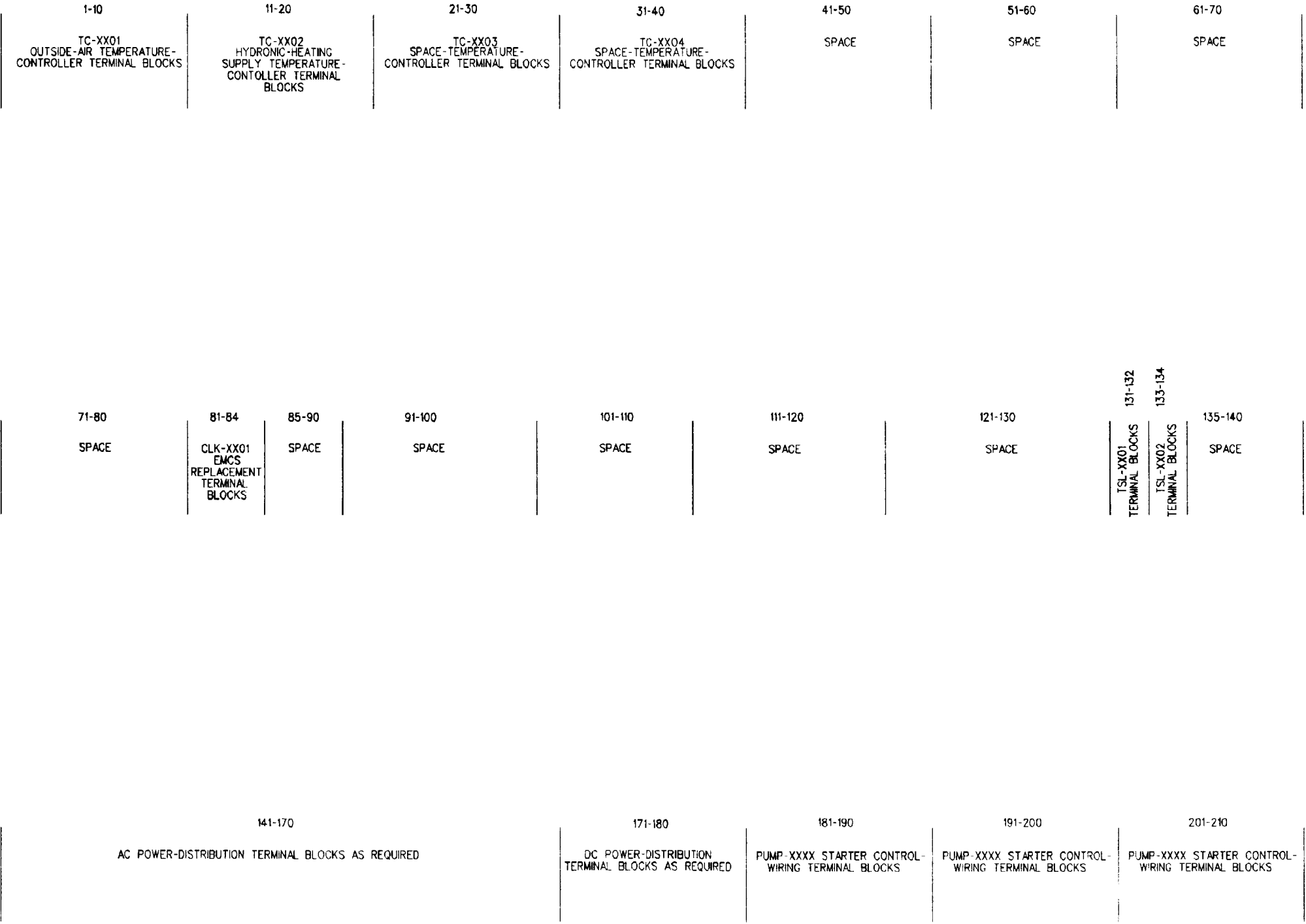


Figure 4-9F. Terminal-block layout for central-plant high-temperature hot-water hydronic-heating system XX control panel.

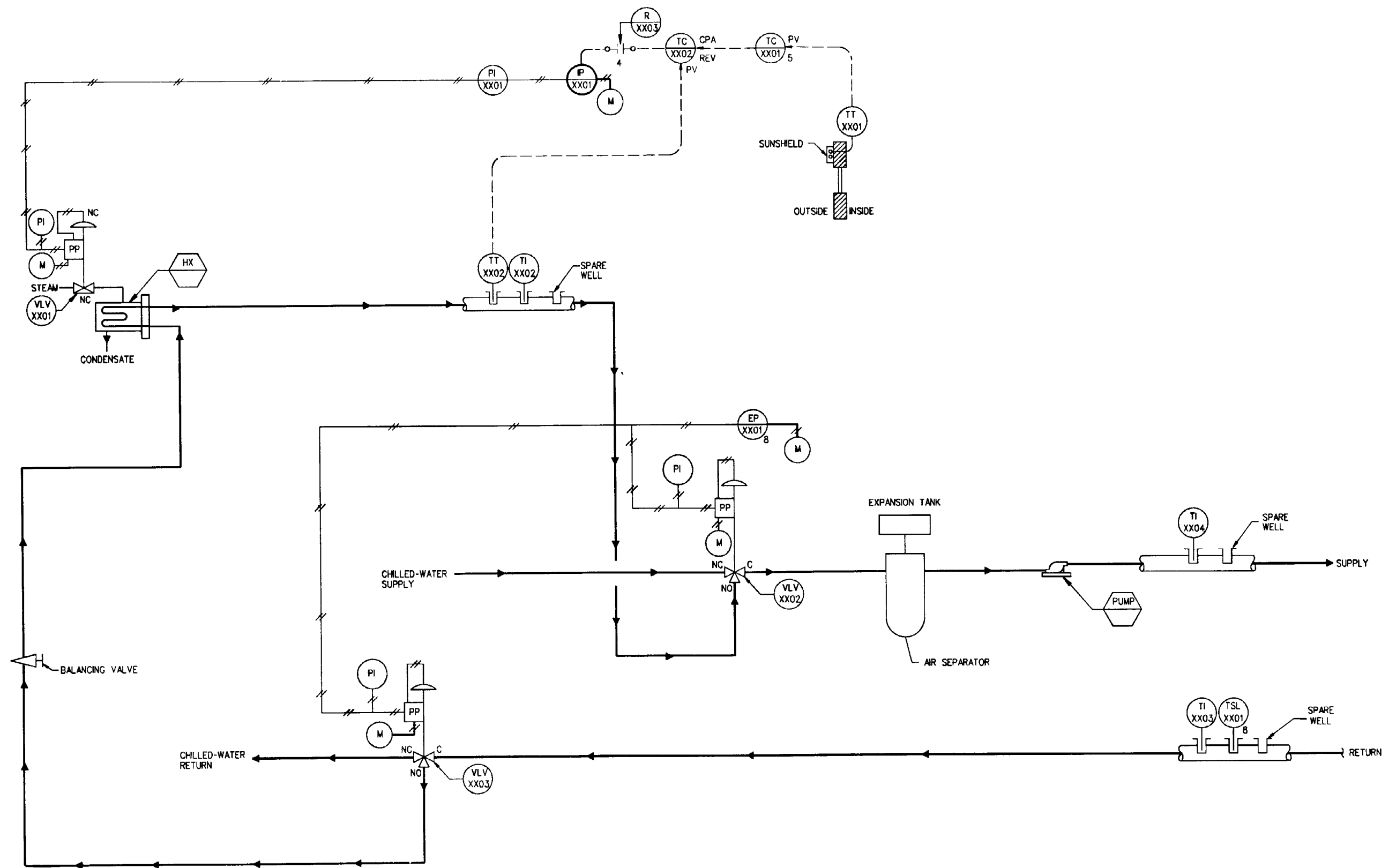
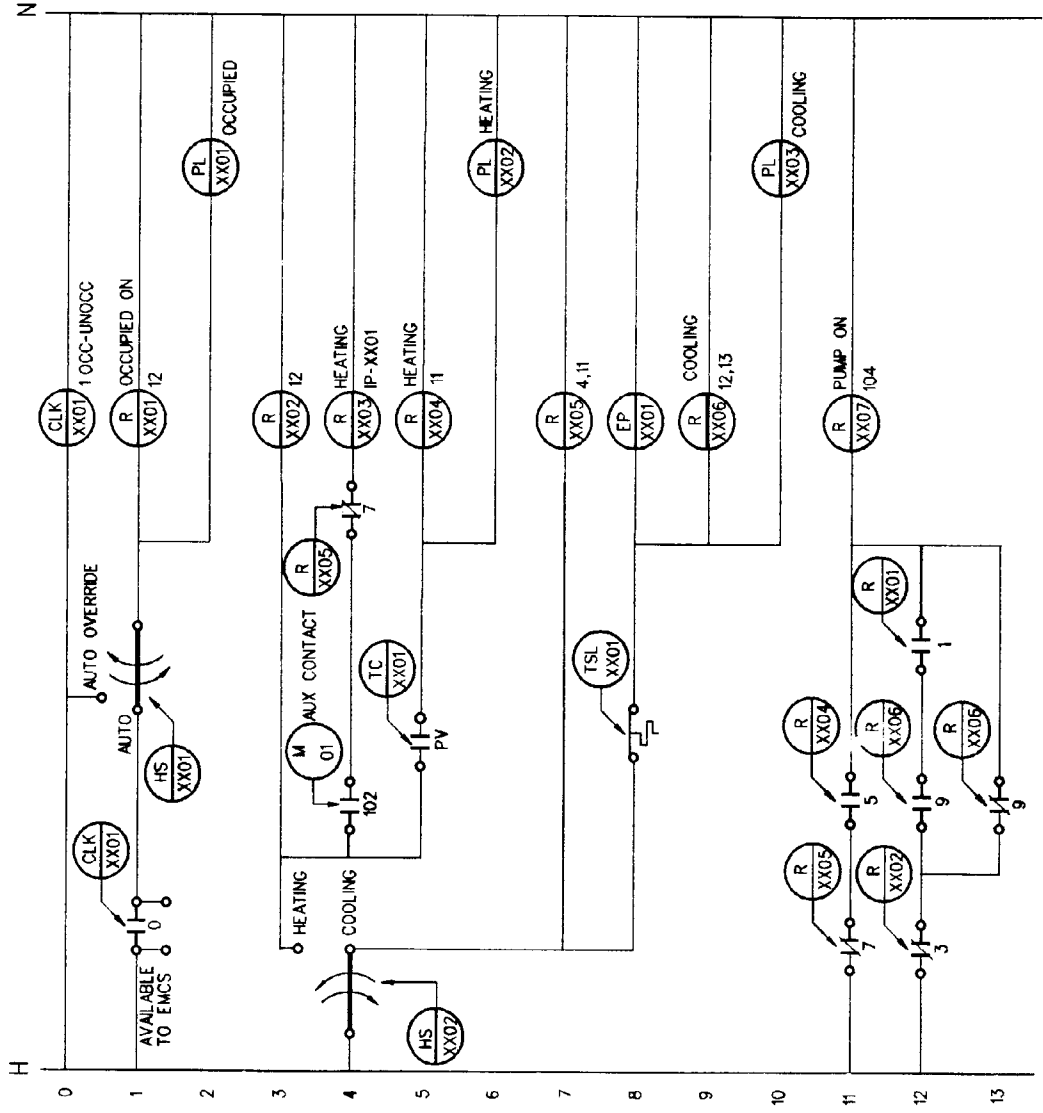


Figure 4-10A. Control-system schematic for central-plant steam dual-temperature hydronic control system XX.



HVAC CONTROL PANEL

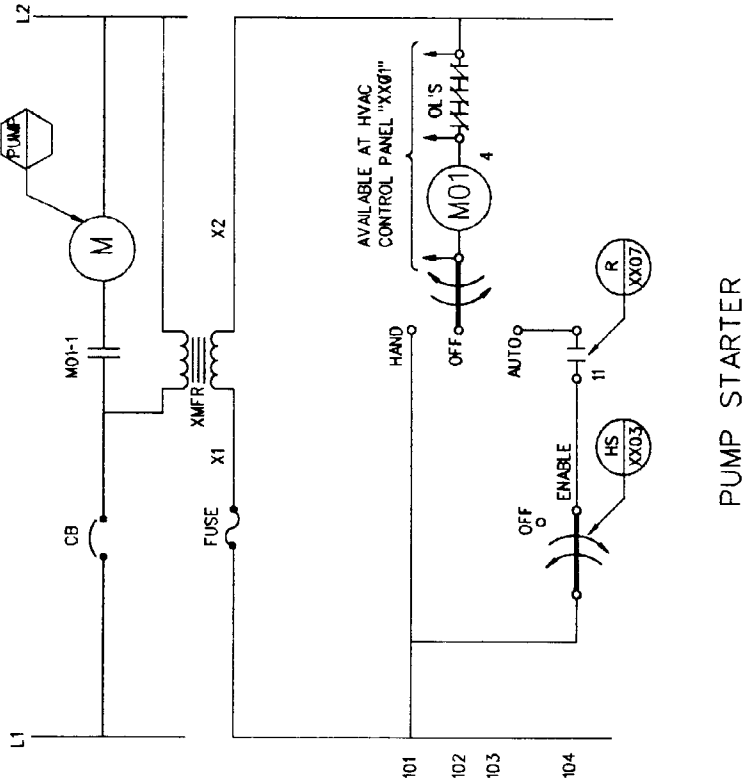


Figure 4-10B. Control-system ladder diagram for central-plant steam dual-temperature hydronic system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
DUAL-TEMPERATURE SUPPLY TEMPERATURE	VLV-XX01	CONVERTOR VALVE	—	3-15	CV-12 CLOSE AGAINST 10 PSIG
	TC-XX01	OUTSIDE-AIR TEMPERATURE CONTROLLER	15°F	-30° TO +130°F	PV-1 CONTACT STARTS PUMP AT 60°F STOPS PUMP AT 62°F MINIMUM OUTPUT-0% MAXIMUM OUTPUT +67%
	TC-XX02	SYSTEM-SUPPLY TEMPERATURE CONTROLLER	OA TEMP-0°F,SUPPLY TEMP-200°F OA TEMP-60°F,SUPPLY TEMP-100°F	100 TO 250°F	—
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30° TO +130°F	—
	TT-XX02	SYSTEM-SUPPLY TEMPERATURE TRANSMITTER	—	100 TO 250°F	—
DUAL-TEMPERATURE CHANGEOVER	VLV-XX02	SUPPLY CHANGEOVER VALVE	—	3-15 PSIG	CV-19 CLOSE AGAINST 30 PSIG
	VLV-XX03	RETURN CHANGEOVER VALVE	—	3-15 PSIG	CV-19 CLOSE AGAINST 30 PSIG
	TSL-XX01	SYSTEM RETURN CHANGEOVER THERMOSTAT	—	30 TO 240°F	CLOSE AT 85°F OPEN AT 90°F
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 1700 HRS M,T,W,Th,F	OPEN: SAT, SUN AND HOLIDAYS

NOTE: OTHER CONTROL DEVICES SUCH AS IPS,RELAYS,AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 4-10C. Equipment for central-plant steam dual-temperature hydronic control system XX.

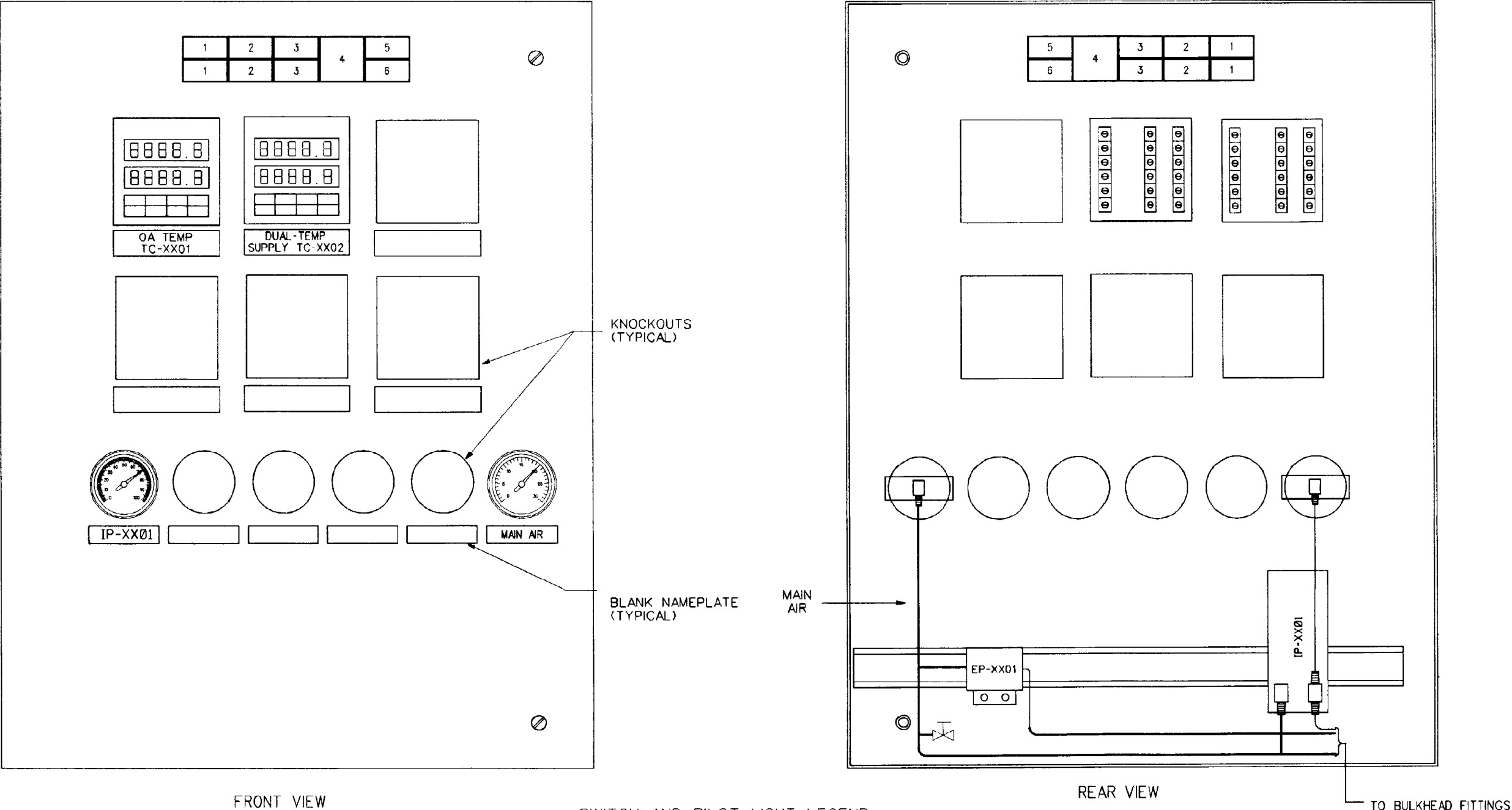


Figure 4-10D. Control-panel interior-door layout for central-plant steam dual-temperature hydronic system XX.

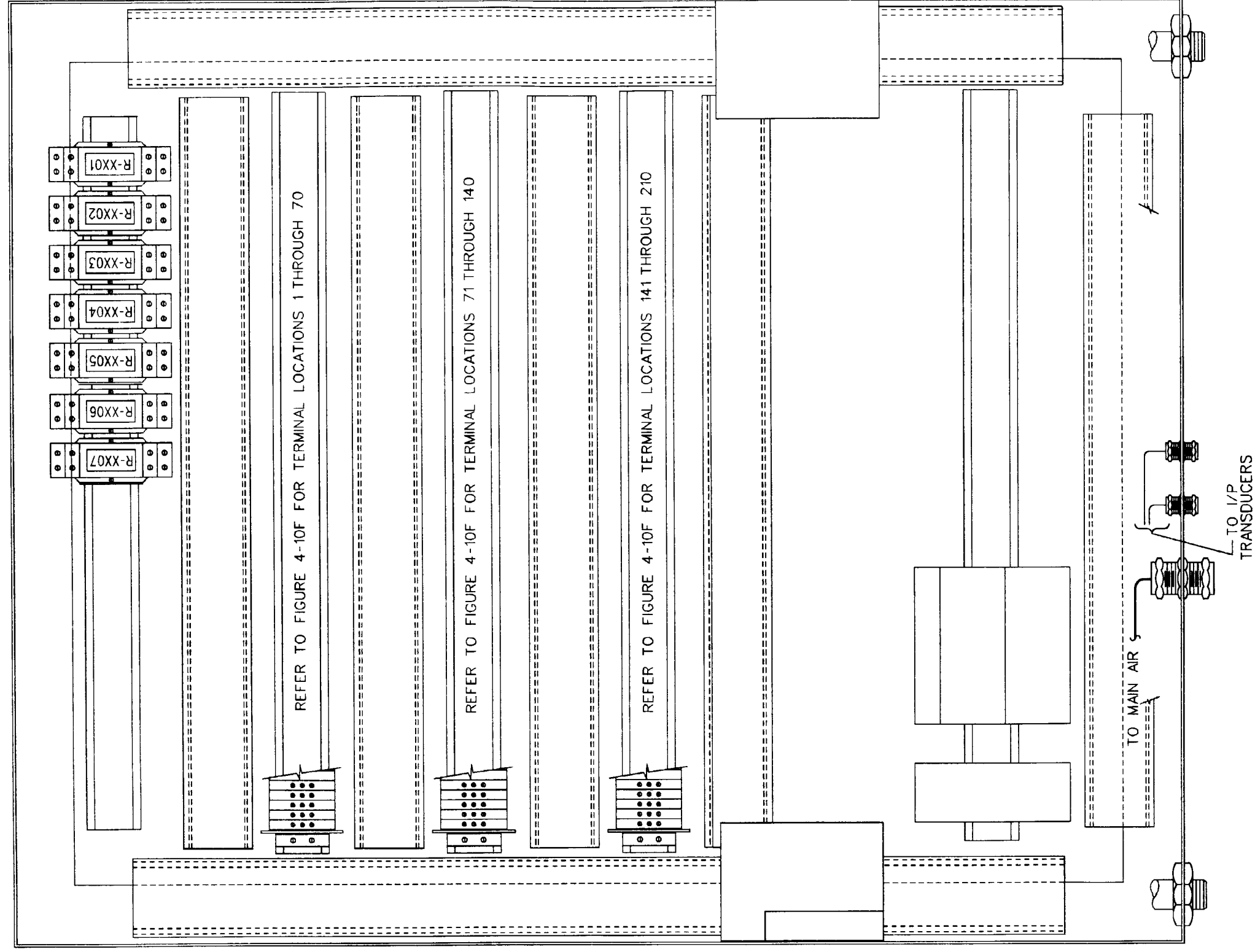


Figure 4-10E. Back-panel layout for central-plant steam dual-temperature hydronic system XX control panel.

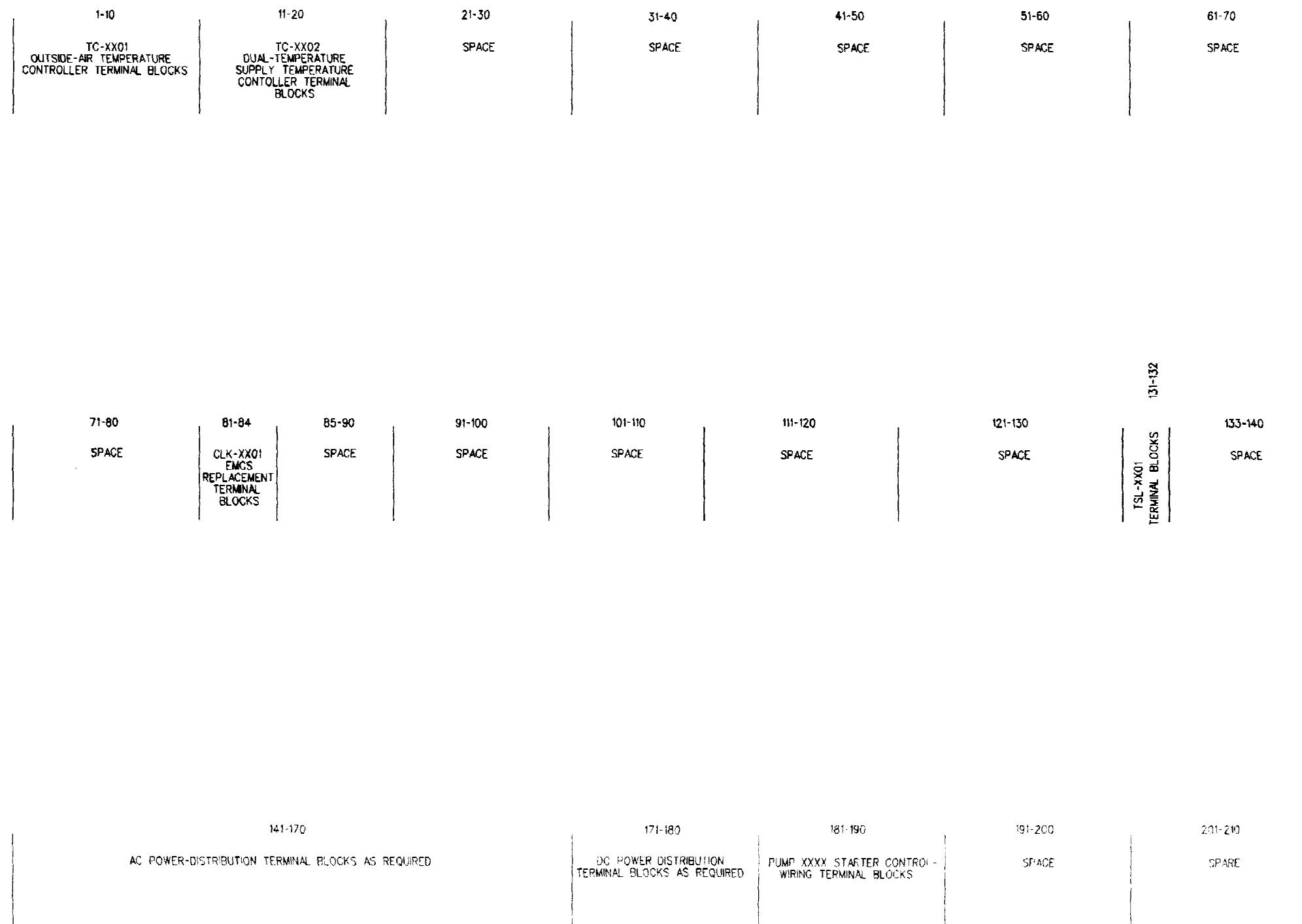


Figure 4-10F. Terminal-block layout for central-plant steam dual-temperature hydronic system XX control panel.

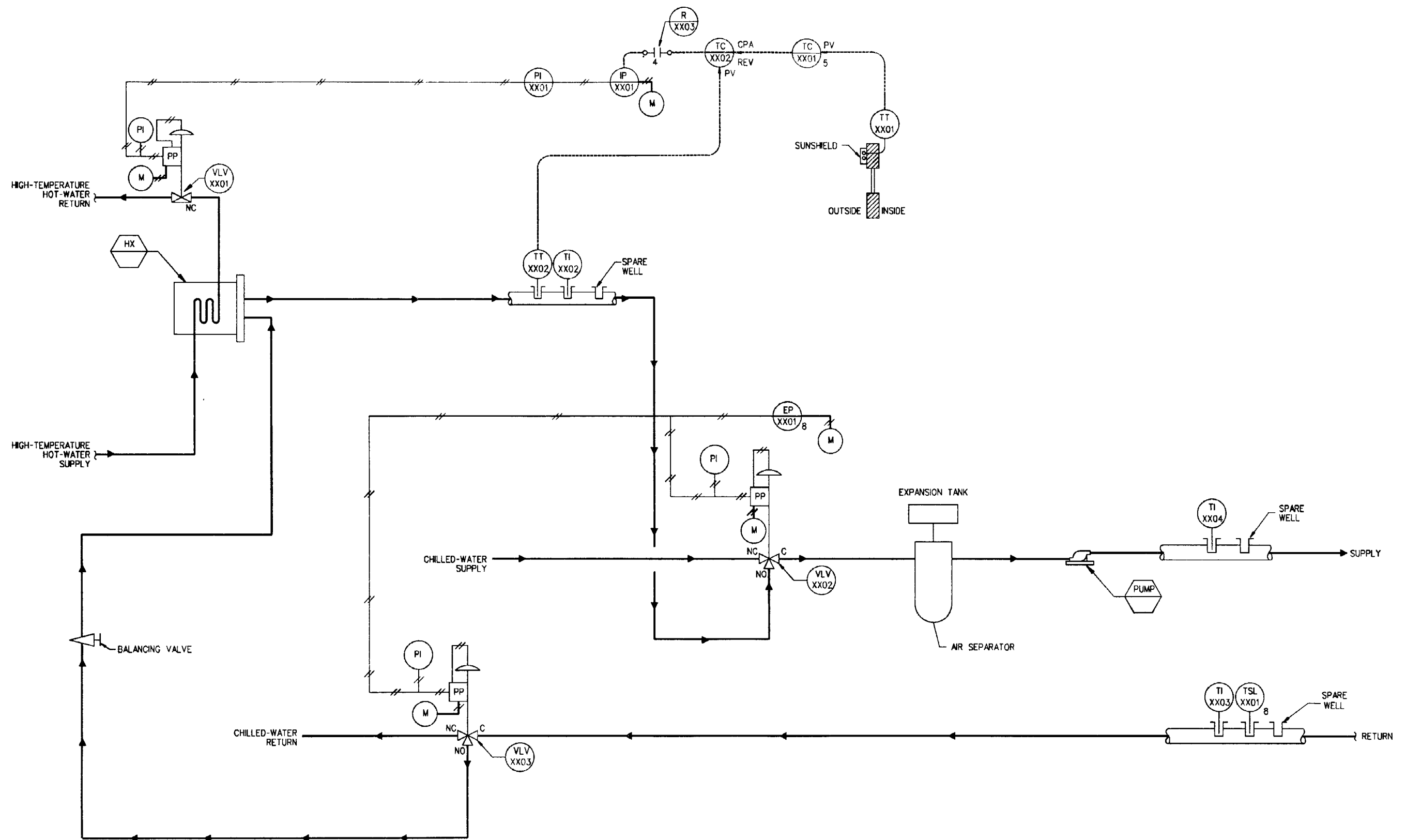
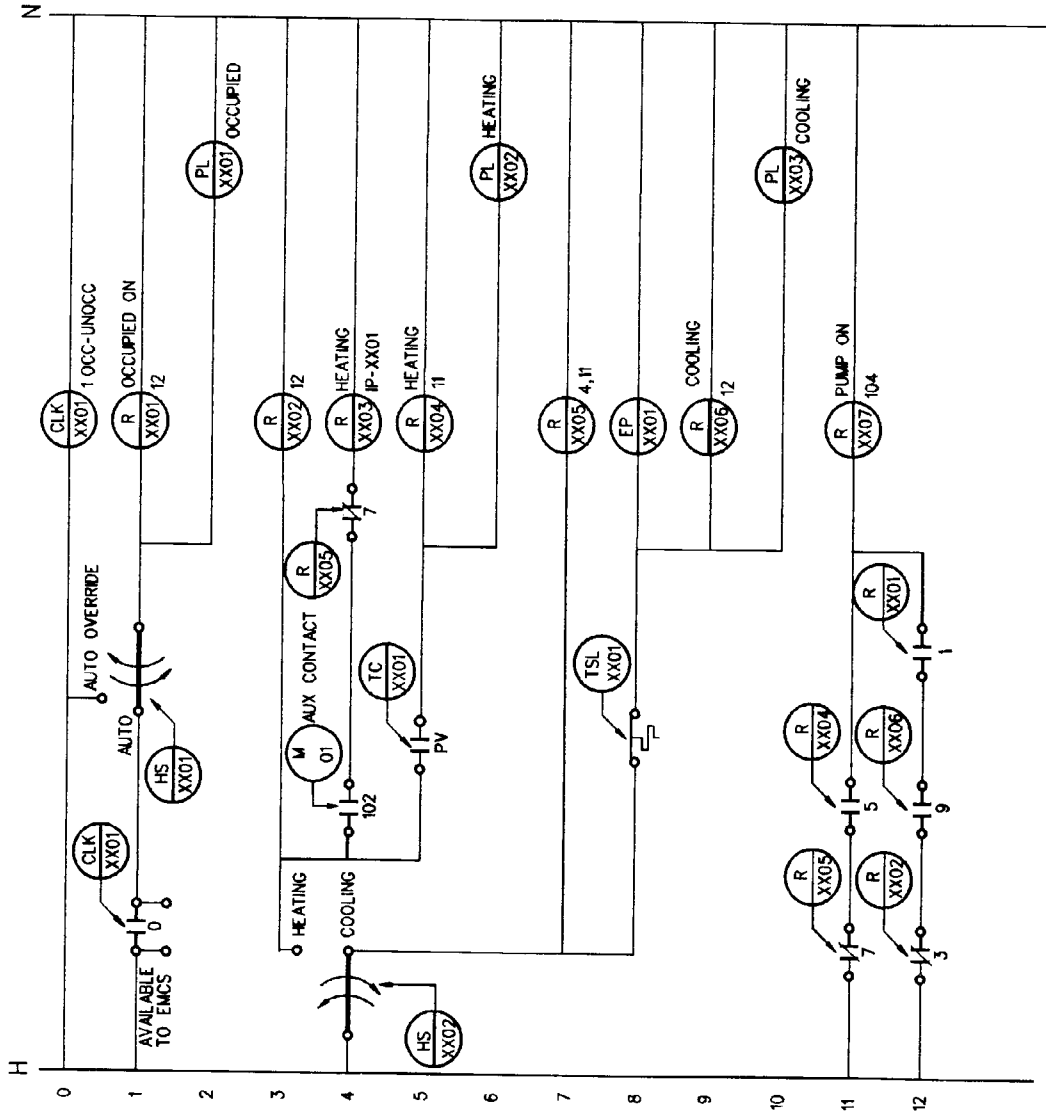
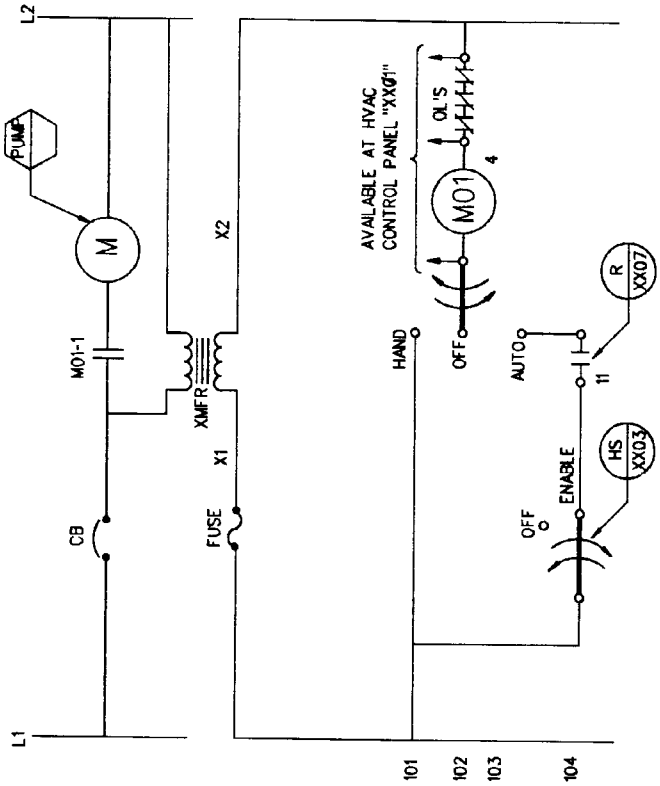


Figure 4-11A. Control-system schematic for central-plant high-temperature hot-water dual-temperature hydronic control system XX.



HVAC CONTROL PANEL



PUMP STARTER

Figure 4-11B. Control-system ladder diagram for central-plant high-temperature hot-water dual-temperature hydronic control system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
DUAL-TEMPERATURE SUPPLY TEMPERATURE	VLV-XX01	CONVERTOR CONTROL VALVE	—	3-15	CV-20 CLOSE AGAINST 120 PSIG
	TC-XX01	OUTSIDE-AIR TEMPERATURE CONTROLLER	15°F PROPORTIONAL BAND-56%	-30° TO +130°F	PV CONTACT STARTS PUMP AT 60°F STOPS PUMP AT 62°F MINIMUM OUTPUT-0% MAXIMUM OUTPUT-67%
	TC-XX02	SYSTEM-SUPPLY TEMPERATURE CONTROLLER	OA TEMP-0°F, SUPPLY TEMP-200°F OA TEMP-60°F, SUPPLY TEMP-100°F	100 TO 250 °F	—
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30° TO +130°F	—
	TT-XX02	SYSTEM-SUPPLY TEMPERATURE TRANSMITTER	—	100 TO 250 °F	—
DUAL-TEMPERATURE CHANGEOVER	VLV-XX02	SUPPLY-CHANGEOVER VALVE	—	3-15 PSIG	CV-19 CLOSE AGAINST 10 PSIG
	VLV-XX03	RETURN-CHANGEOVER VALVE	—	3-15 PSIG	CV-19 CLOSE AGAINST 10 PSIG
	TSL-XX01	SYSTEM-RETURN CHANGEOVER THERMOSTAT	—	30 TO 240 °F	CLOSE AT 85 °F OPEN AT 90 °F
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS. OPEN: 1700 HRS M.T.W.TH.F	OPEN: SAT. SUN AND HOLIDAYS

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS, AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 4-11C. Equipment for central-plant high-temperature hot-water dual-temperature hydronic control system XX.

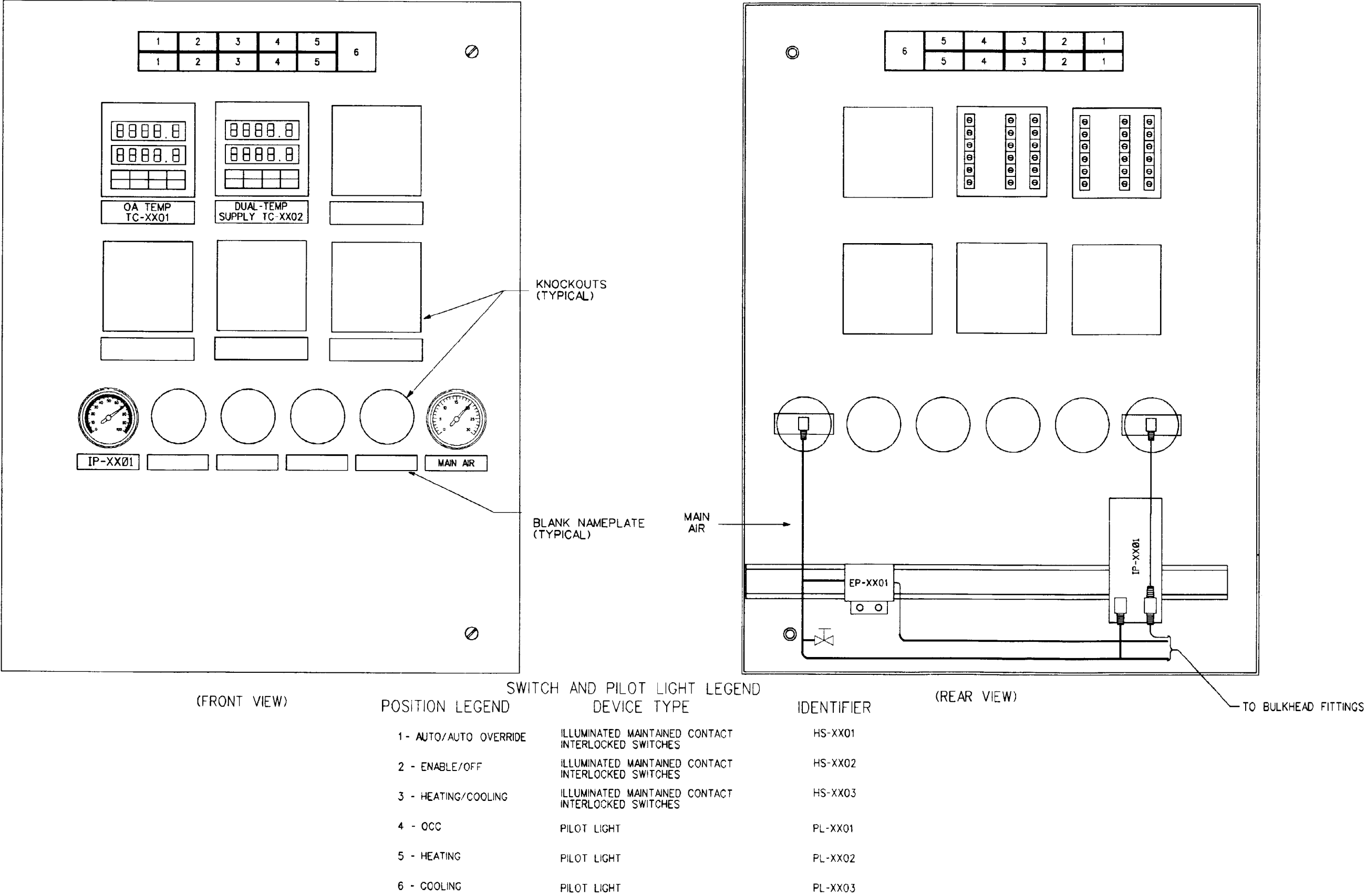


Figure 4-11D. Control-panel interior-door layout for central-plant high-temperature hot-water dual-temperature hydronic control system XX.

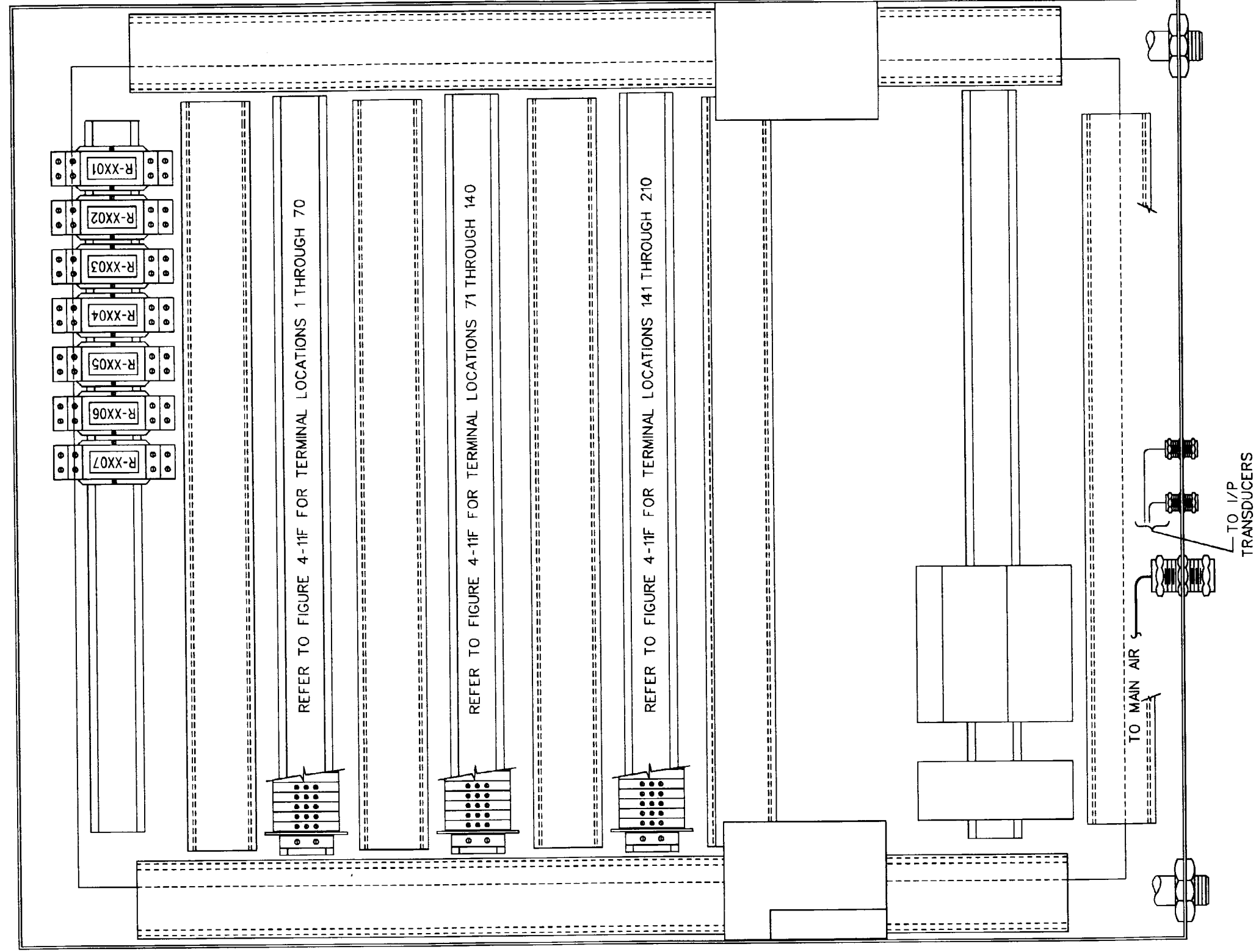


Figure 4-11E. Back-panel layout for central-plant high-temperature hot-water dual-temperature hydronic control system XX control panel.

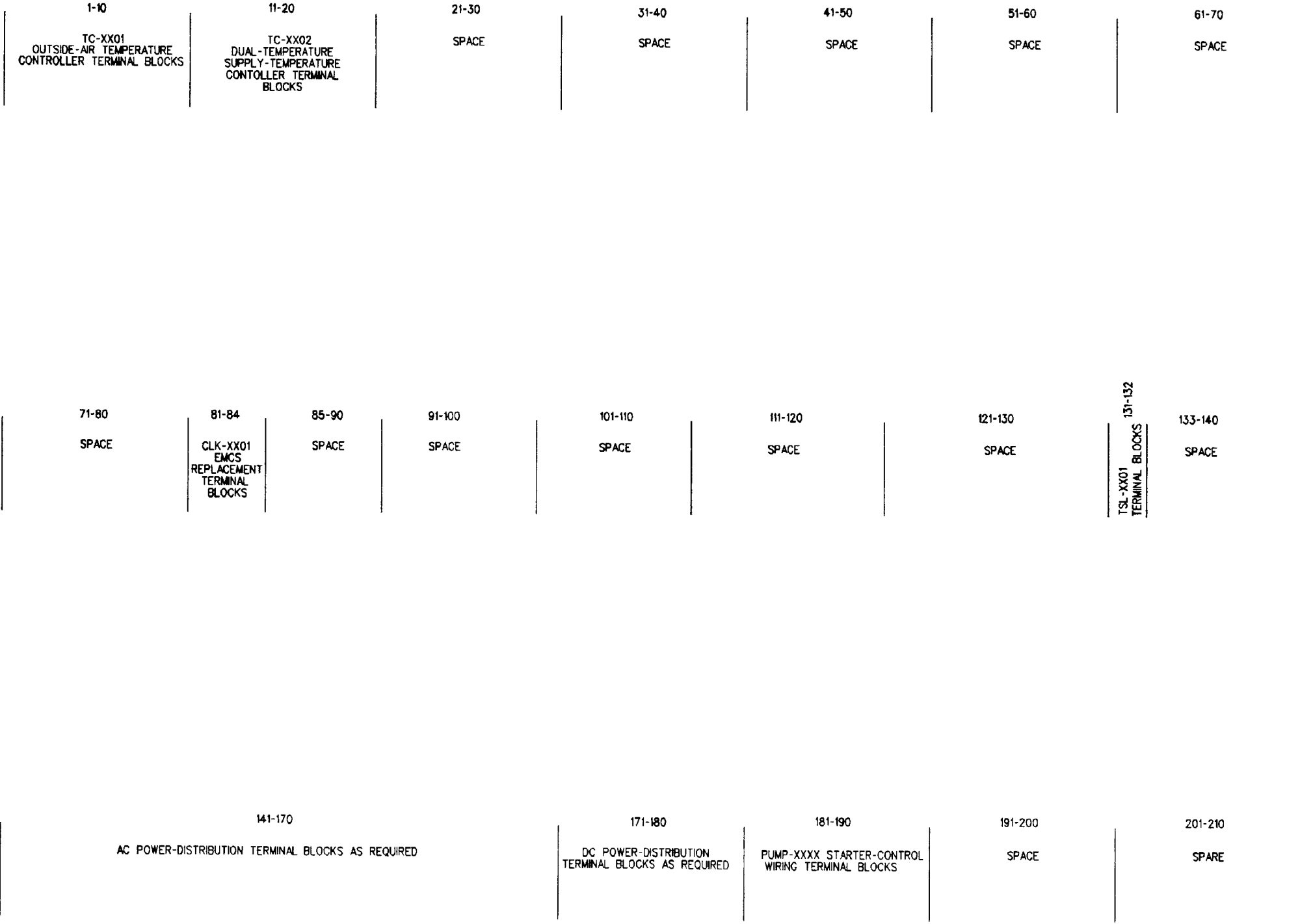


Figure 4-11F. Terminal-block layout for central-plant high-temperature hot-water dual-temperature hydronic control system XX control panel.

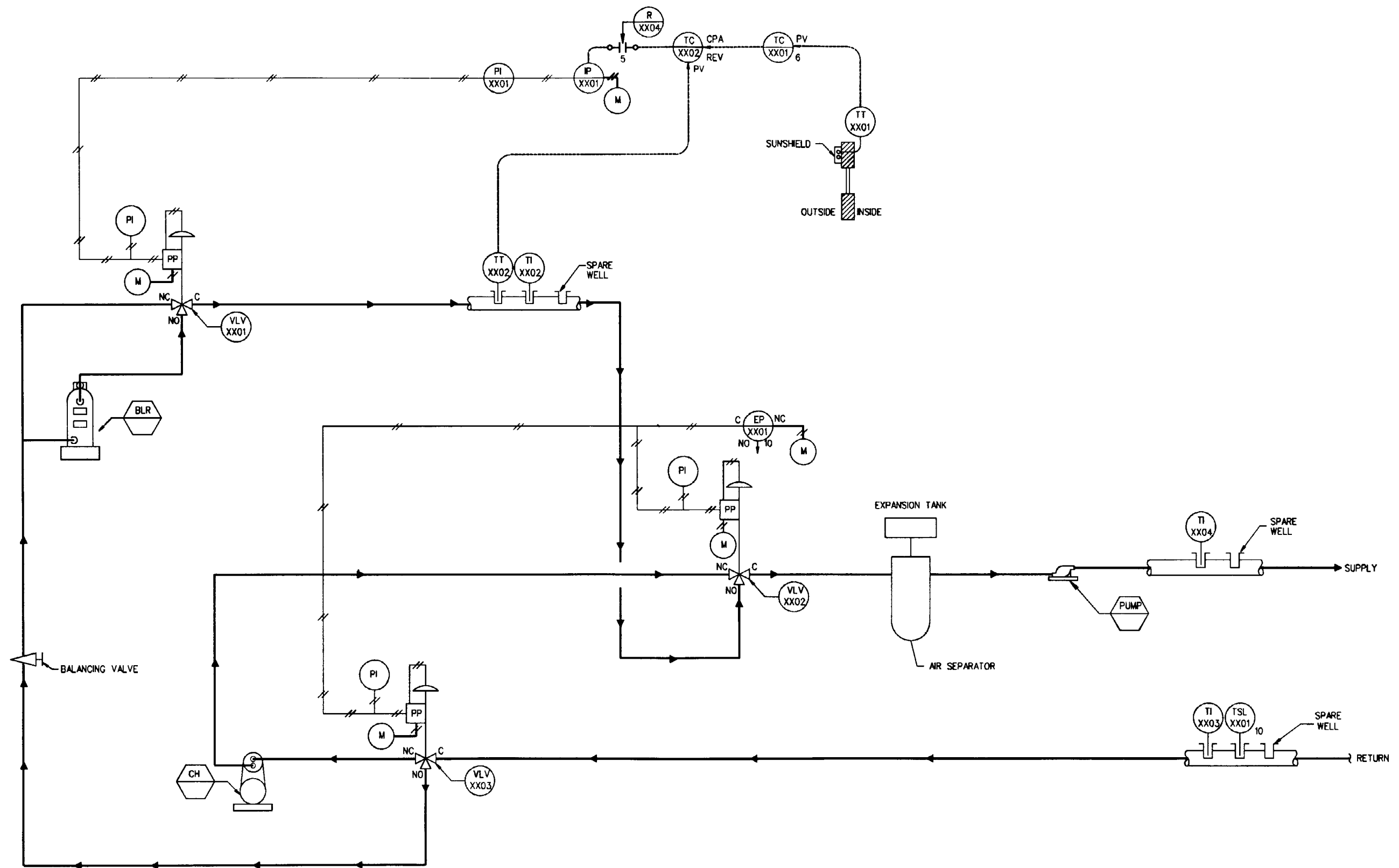


Figure 4-12A. Control-system schematic for single-building dual-temperature hydronic system XX.

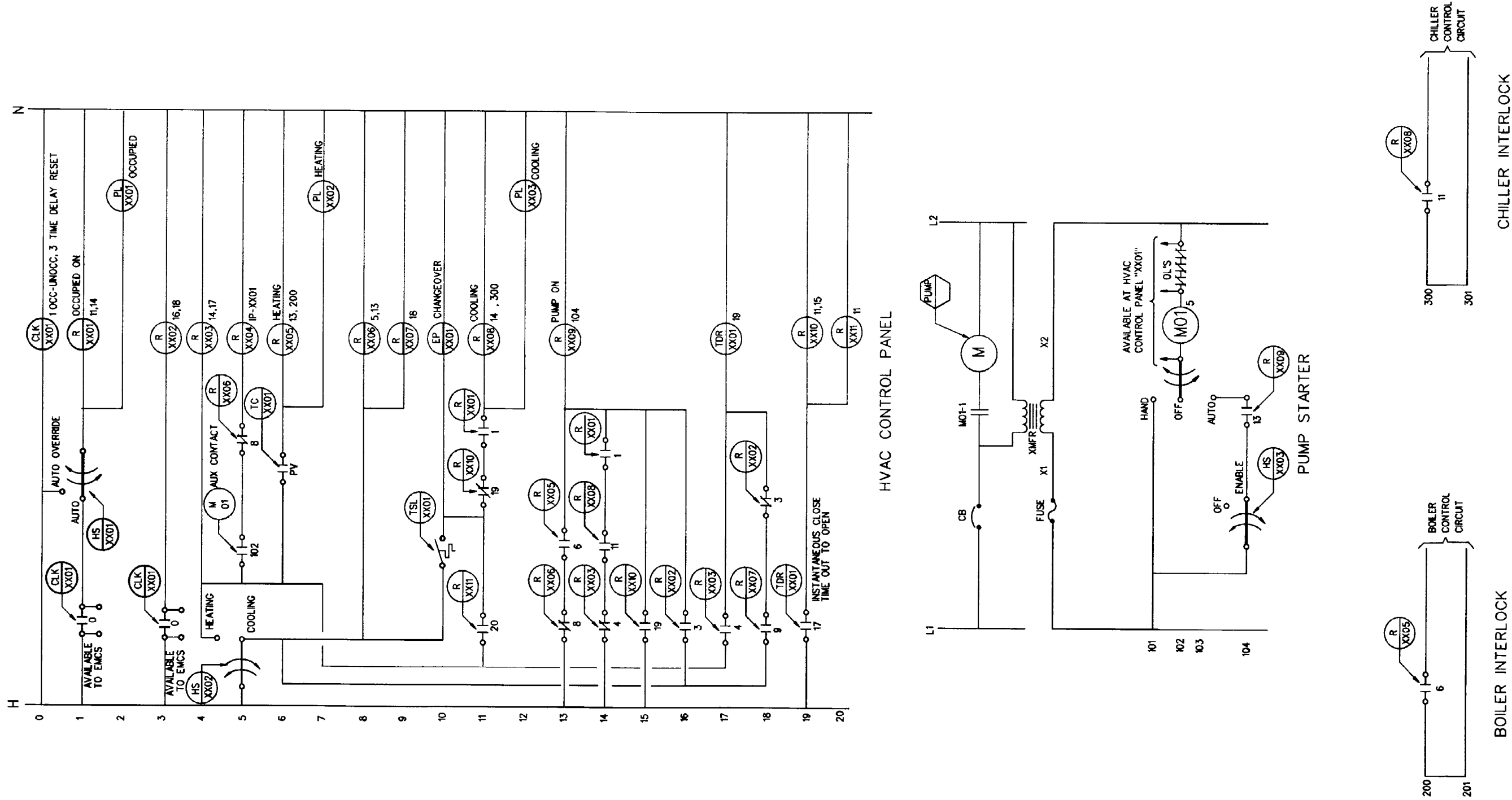


Figure 4-12B. Control-system ladder diagram for single-building dual-temperature hydronic system XX.

LOOP-CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
DUAL-TEMPERATURE SUPPLY TEMPERATURE	VLV-XX01	SYSTEM VALVE	—	3-15 PSIG	CV-7 CLOSE AGAINST 10 PSIG
	TC-XX01	OUTSIDE-AIR TEMPERATURE CONTROLLER	15°F PORPORTIONAL BAND=56%	-30° TO +130°F	PV-1 CONTACT STARTS PUMP AT 60°F STOPS PUMP AT 62°F MINIMUM OUTPUT=0% MAXIMUM OUTPUT=67%
	TC-XX02	SYSTEM-SUPPLY TEMPERATURE CONTROLLER	OA TEMP=40°F, SUPPLY TEMP=200°F OA TEMP=60°F, SUPPLY TEMP=100°F	100 TO 250 °F	—
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30° TO +130°F	—
	TT-XX02	SYSTEM-SUPPLY TEMPERATURE TRANSMITTER	—	100 TO 250 °F	—
DUAL-TEMPERATURE CHANGEOVER	VLV-XX02	SUPPLY-CHANGEOVER VALVE	—	3-15 PSIG	CV-19 CLOSE AGAINST 10 PSIG
	VLV-XX03	RETURN-CHANGEOVER VALVE	—	3-15 PSIG	CV-19 CLOSE AGAINST 10 PSIG
	TSL-XX01	SYSTEM-RETURN CHANGEOVER THERMOSTAT	—	30 TO 240 °F	PV CONTACT CLOSE AT 85°F OPEN AT 90°F
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS., OPEN: 1700 HRS. M.T.W.TH.F	OPEN: SAT., SUN AND HOLIDAYS
TIME-DELAY RESET	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS., OPEN: 1700 HRS. M.T.W.TH.F	OPEN: SAT., SUN AND HOLIDAYS

NOTE: OTHER DEVICES SUCH AS IPS AND RELAYS ARE NOT SHOWN

Figure 4-12C. Equipment for single-building dual-temperature hydronic control system XX.

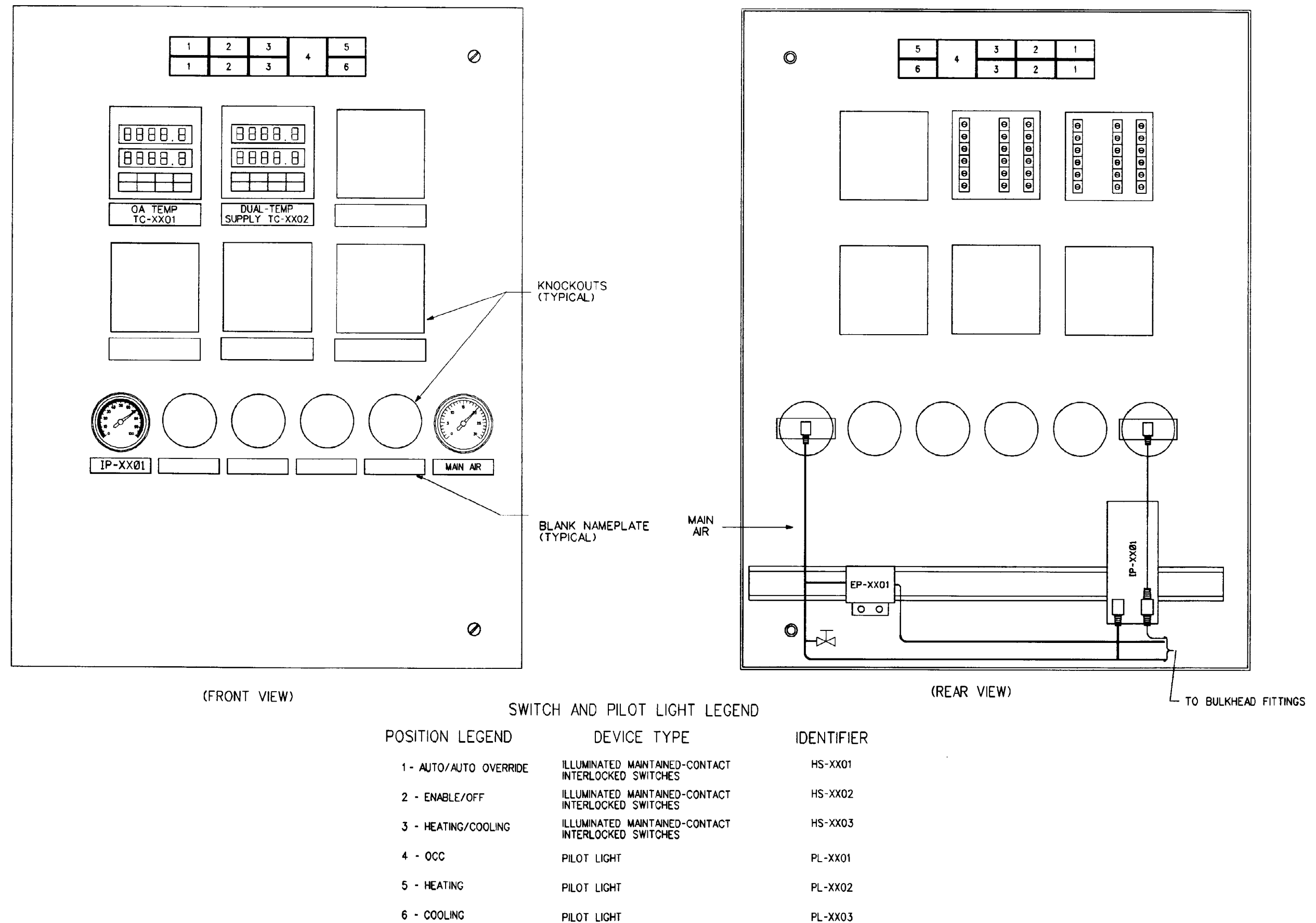


Figure 4-12D. Control-panel interior-door layout for single-building dual-temperature hydronic system XX.

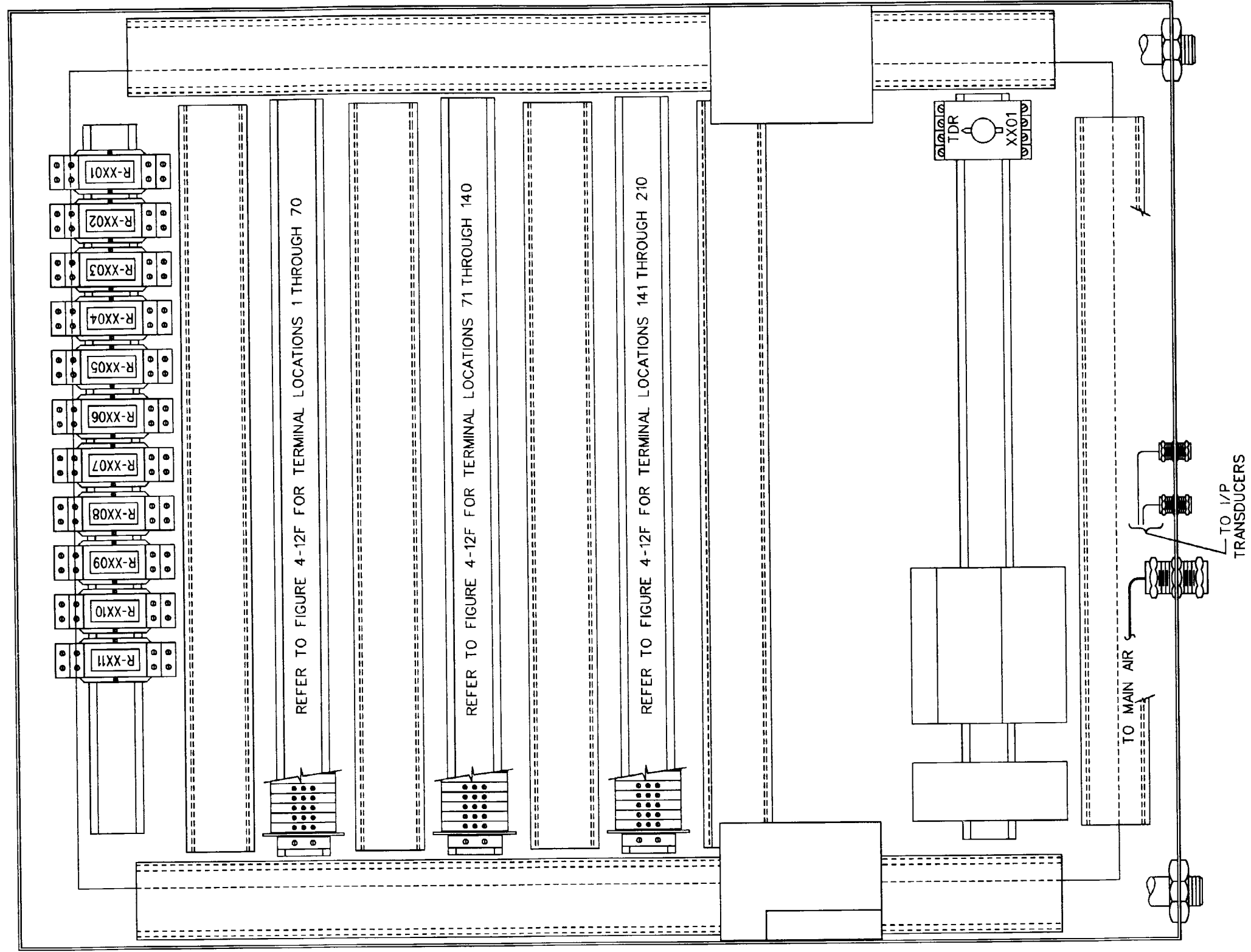


Figure 4-12E. Back-panel layout for single-building dual-temperature hydronic system XX control panel.

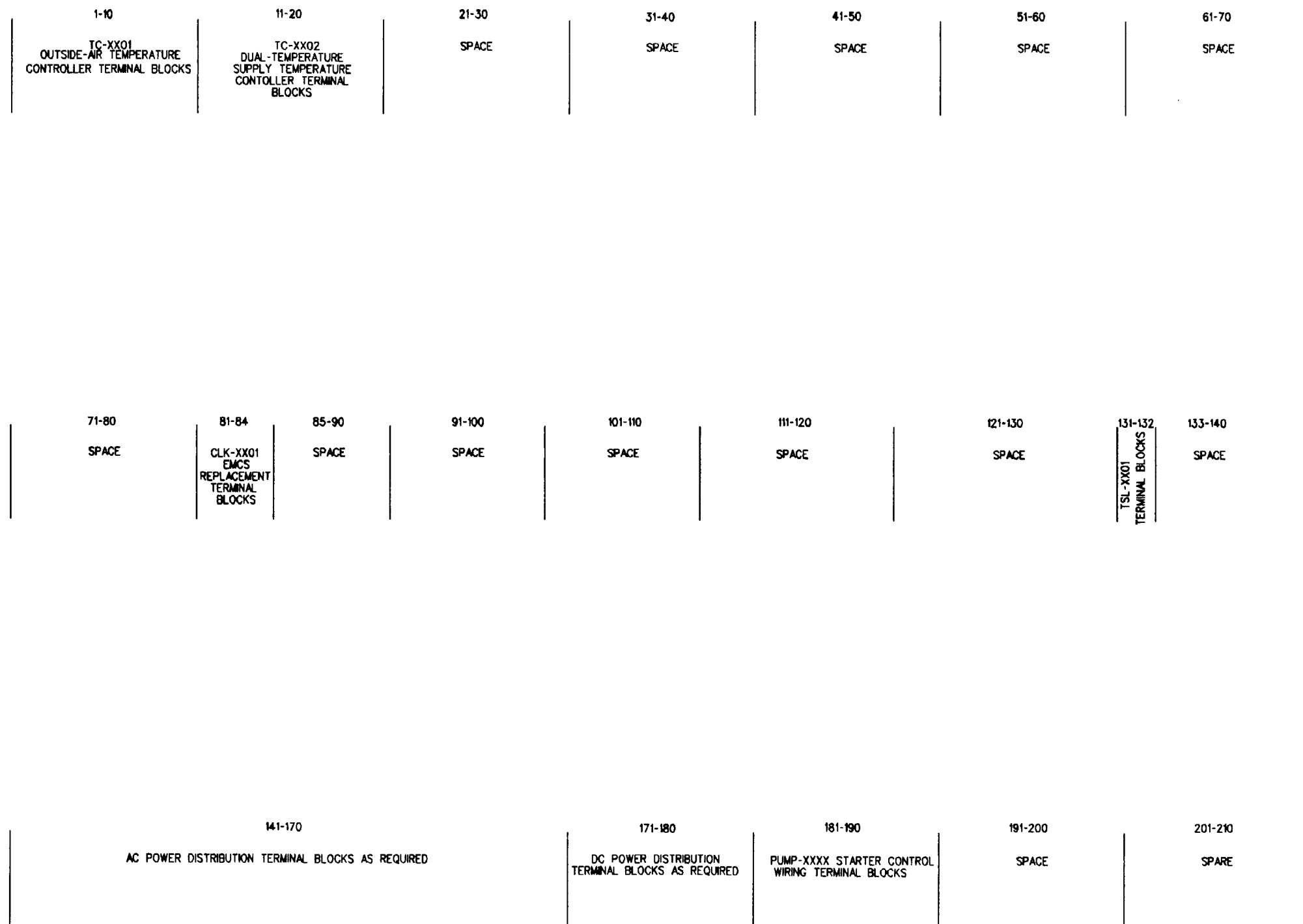


Figure 4-12F. Terminal-block layout for single-building dual-temperature hydronic system XX control panel.

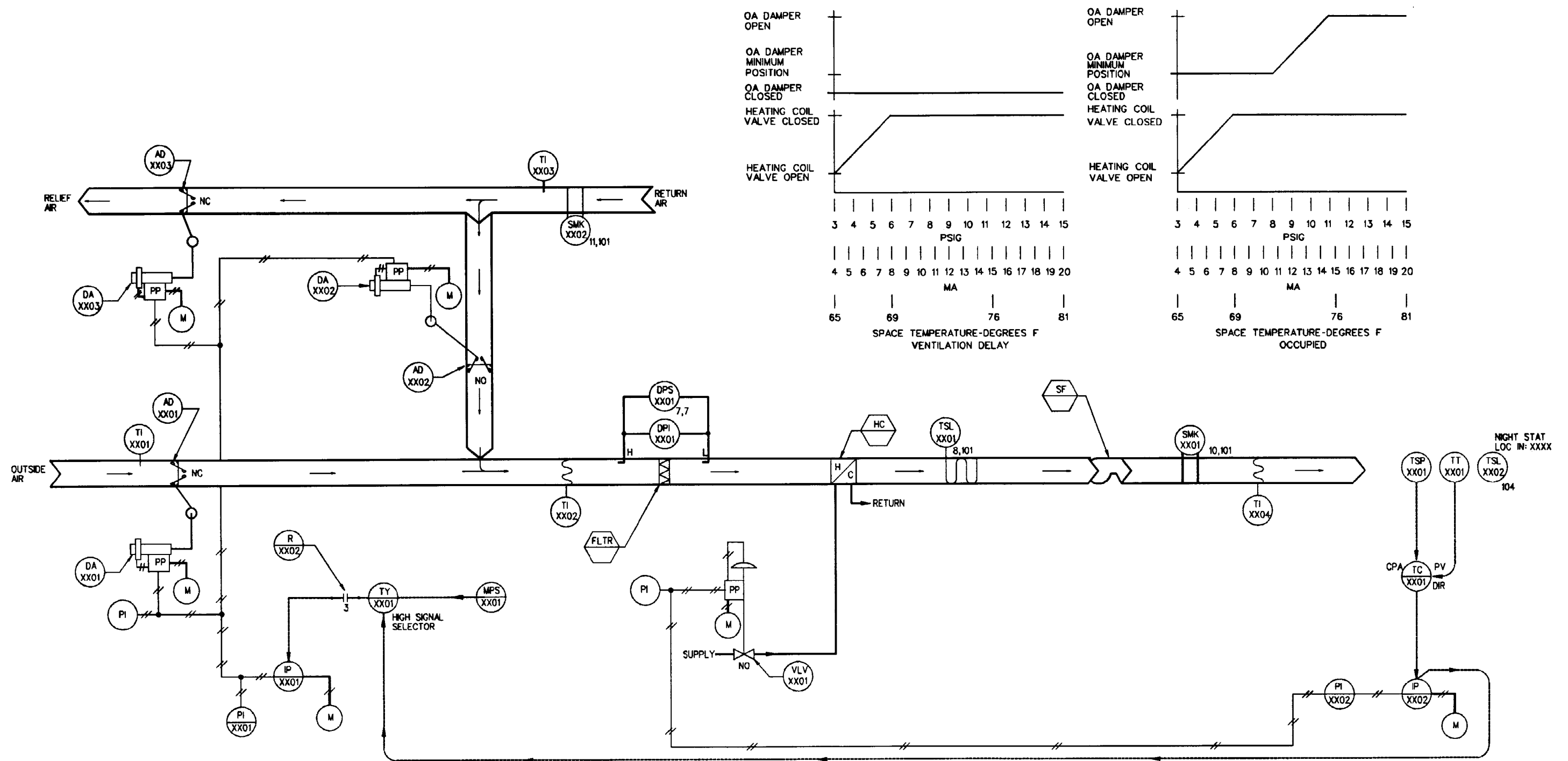


Figure 4-13A. Control-system schematic for heating-and-ventilating system XX.

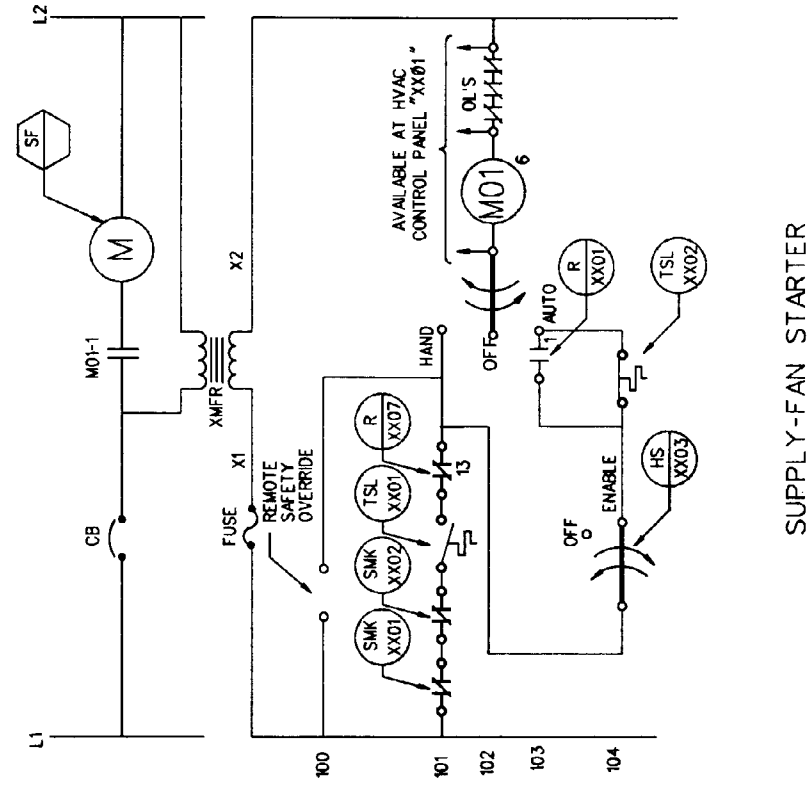
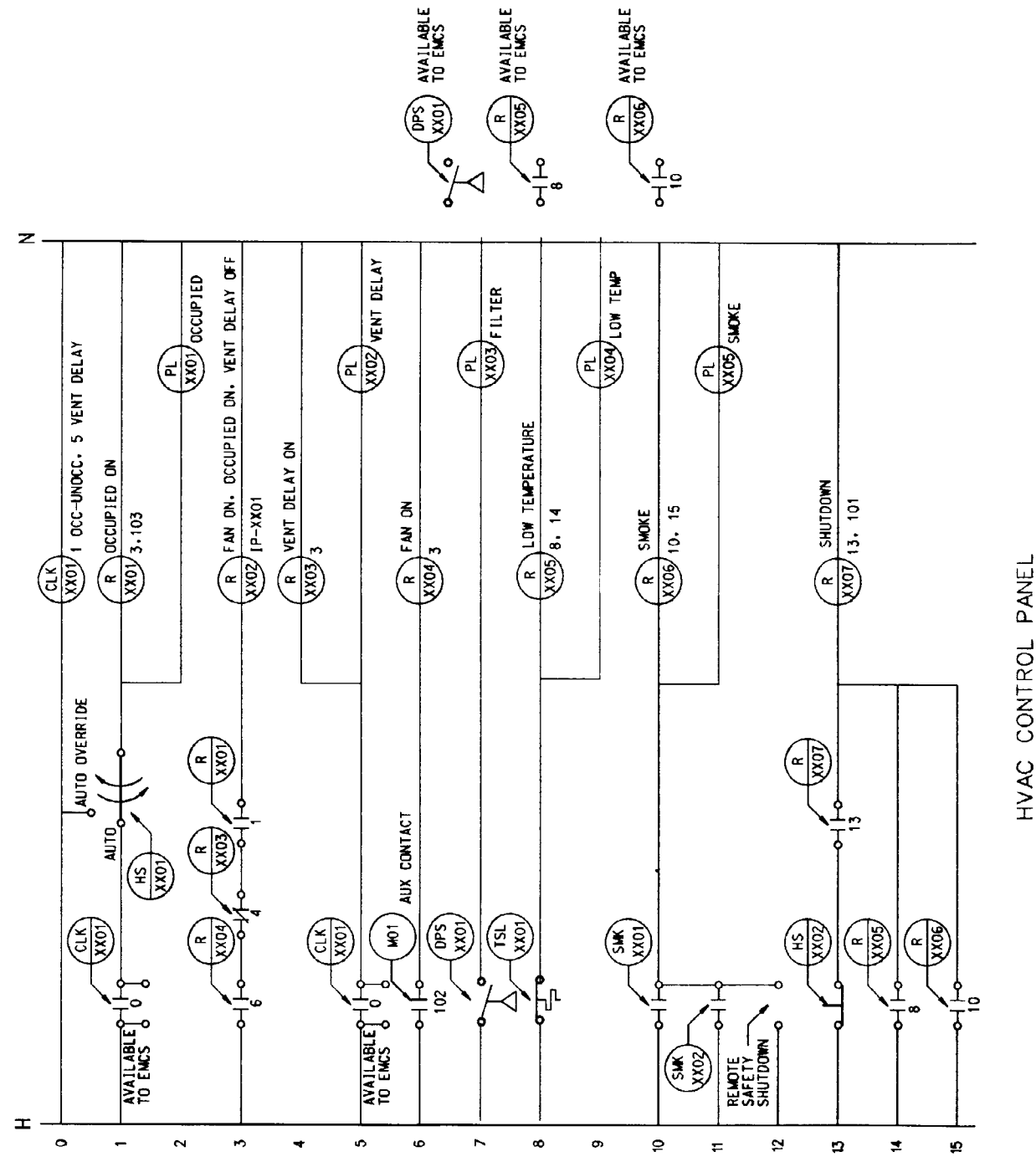
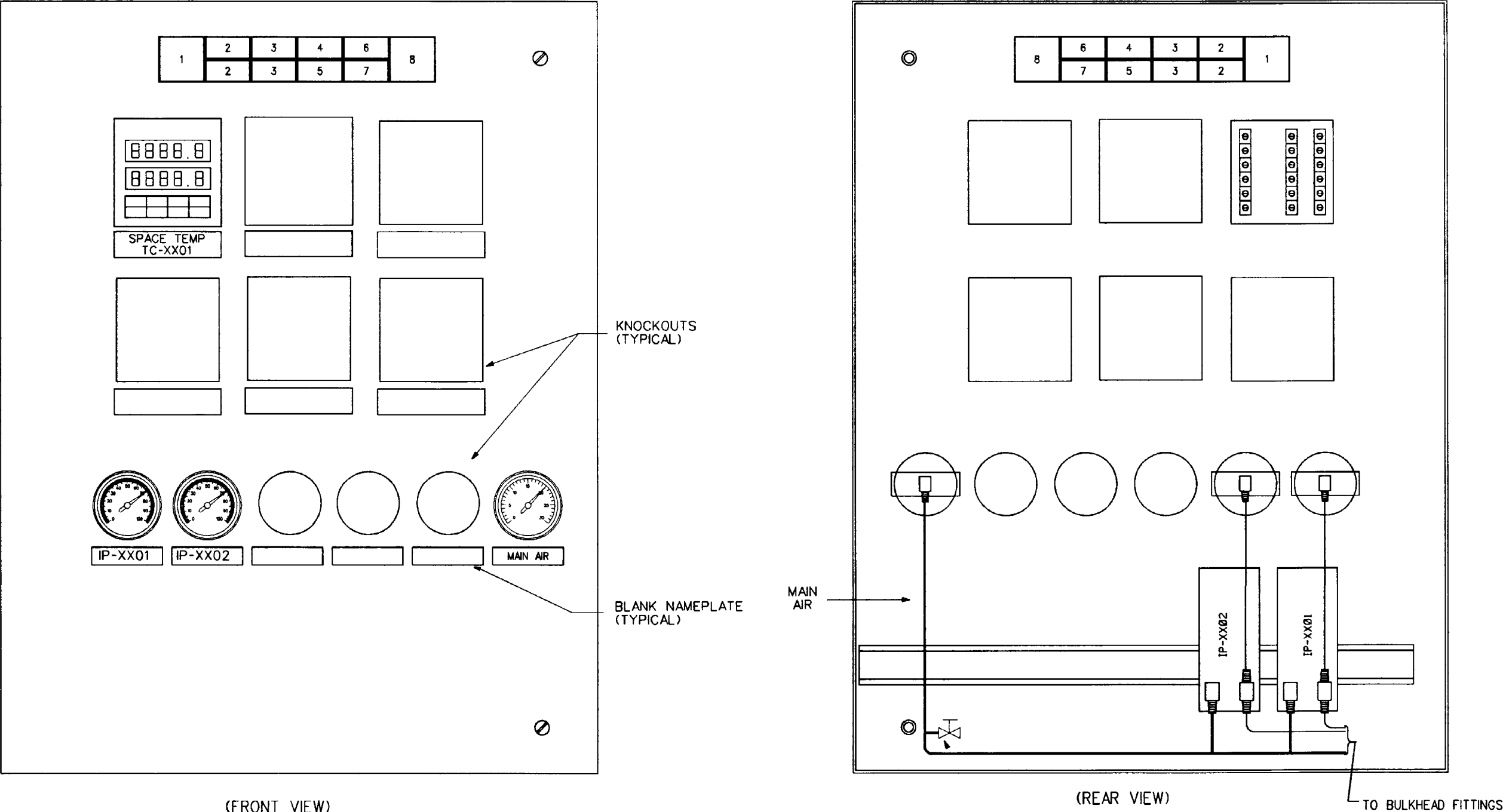


Figure 4-13B. Control-system ladder diagram for heating-and-ventilating system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
SPACE TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	7-11 PSIG	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM
	TSL-XX01	LOW-TEMPERATURE PROTECTION THERMOSTAT	35°F	—	—
	VLV-XX01	HEATING-COIL VALVE	—	3-6 PSIG	CV=7 CLOSE AGAINST 20 PSIG
	TC-XX01	SPACE-TEMPERATURE CONTROLLER	SET POINT =73°F PROP. BAND =45.7% MAN. RESET =50%	50 TO 85°F	SET MAXIMUM LIMITS AVAILABLE TO OCCUPANT BY TSP-XX01 AT 66 TO 72°F
	TT-XX01	SPACE-TEMPERATURE TRANSMITTER	—	50 TO 85°F	—
	TSP-XX01	TEMPERATURE-SETPOINT DEVICES	4ma=50°F 20ma=85°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M.T.W.TH.F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M.T.W.TH.F	

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 4-13C. Equipment for heating-and-ventilating control system XX.



POSITION LEGEND

- 1 - RESET
- 2 - AUTO/AUTO OVERRIDE
- 3 - ENABLE/OFF
- 4 - LOW TEMP
- 5 - SMOKE

DEVICE TYPE

- NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH
- ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES
- ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES
- PILOT LIGHT
- PILOT LIGHT

IDENTIFIER

- HS-XX02
- HS-XX01
- HS-XX03
- PL-XX04
- PL-XX05

SWITCH AND PILOT LIGHT LEGEND

POSITION LEGEND

- 8 - FILTER
- 7 - OCC
- 8 - VENT DELAY

DEVICE TYPE

- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT

IDENTIFIER

- PL-XX03
- PL-XX01
- PL-XX02

Figure 4-13D. Interior-door layout for heating-and-ventilating system XX control panel.

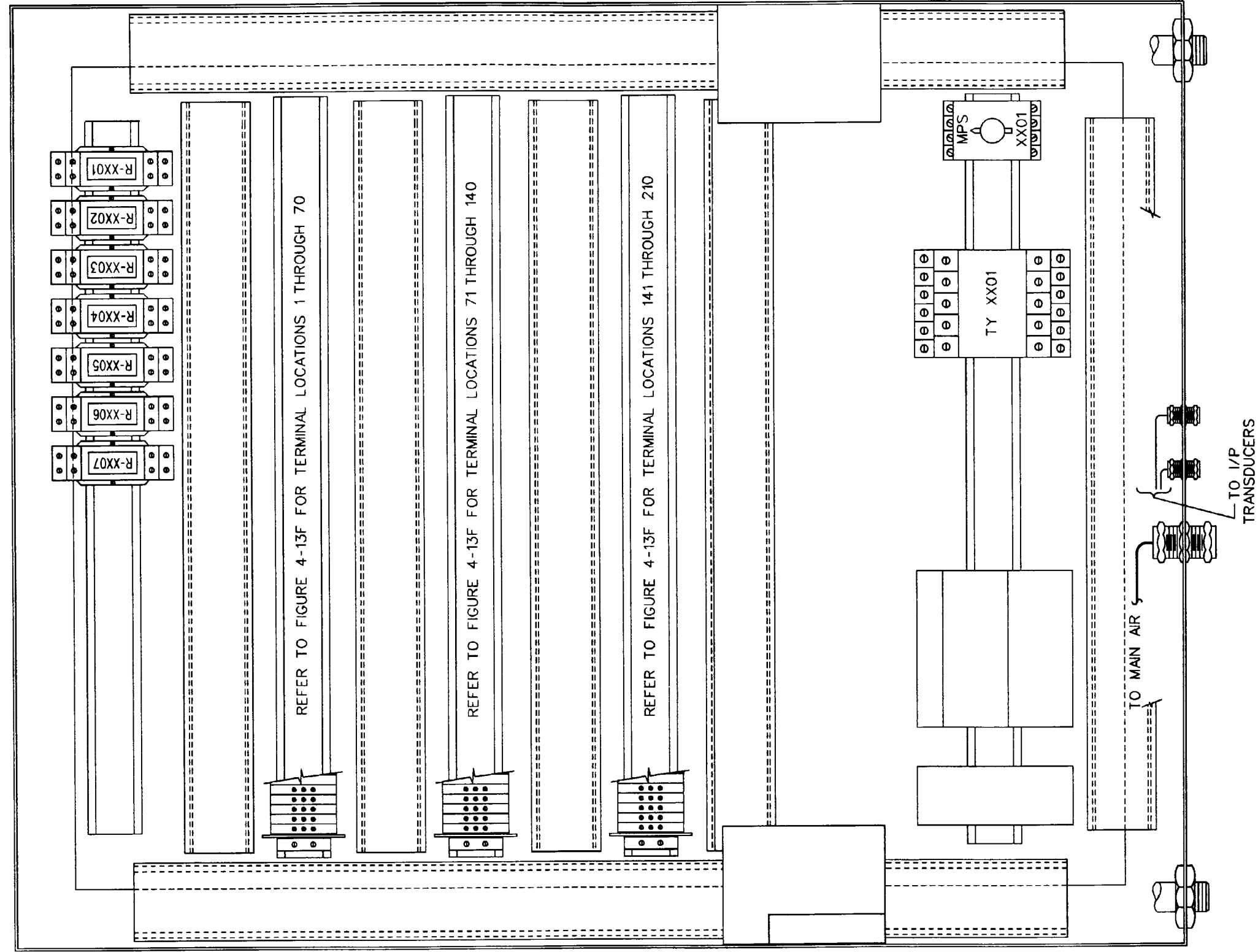


Figure 4-13E. Back-panel layout for heating-and-ventilating system XX control panel.

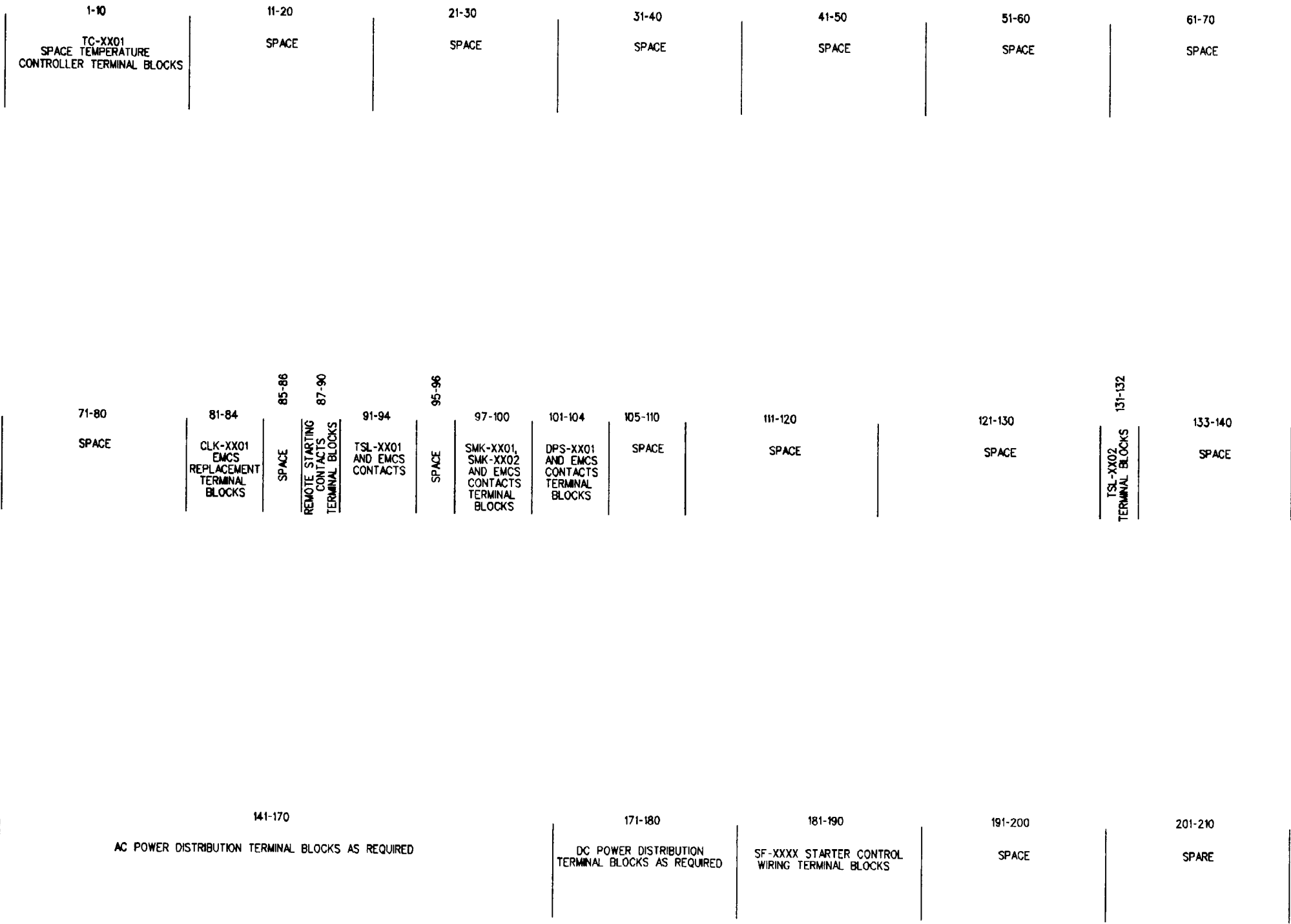


Figure 4-13F. Terminal-block layout for heating-and-ventilating system XX control panel.

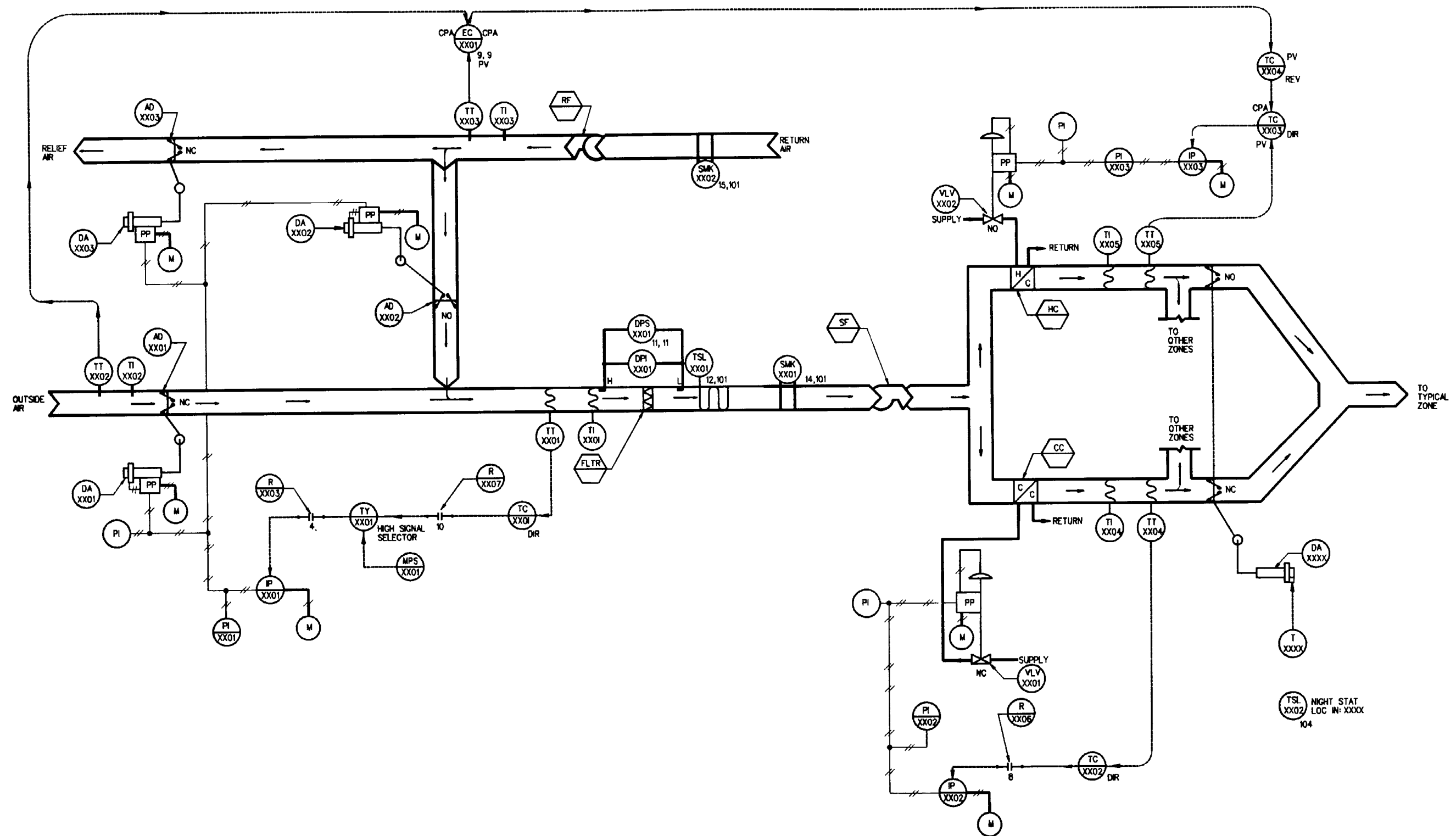
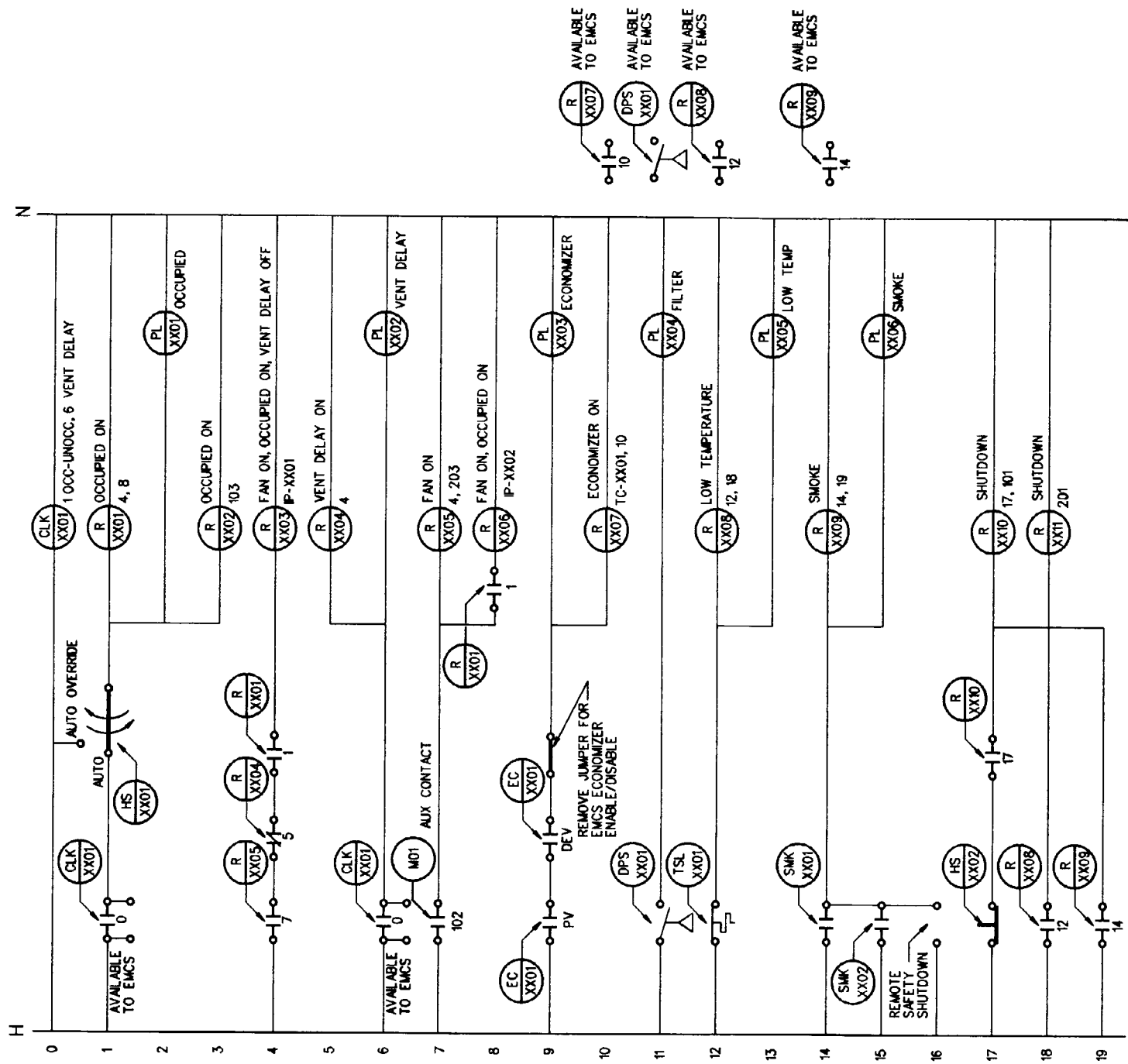
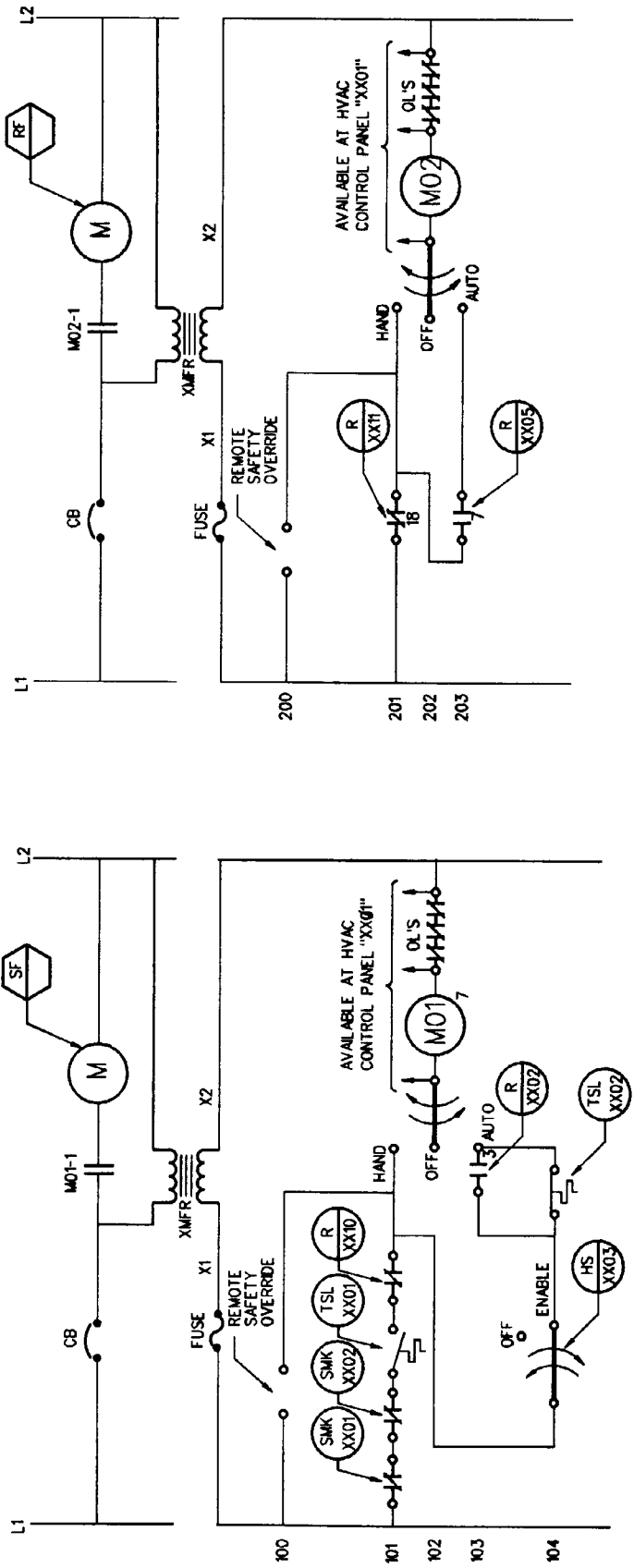


Figure 4-14A. Control-system schematic for multizone HVAC system XX.



HVAC CONTROL PANEL



SUPPLY-FAN STARTER

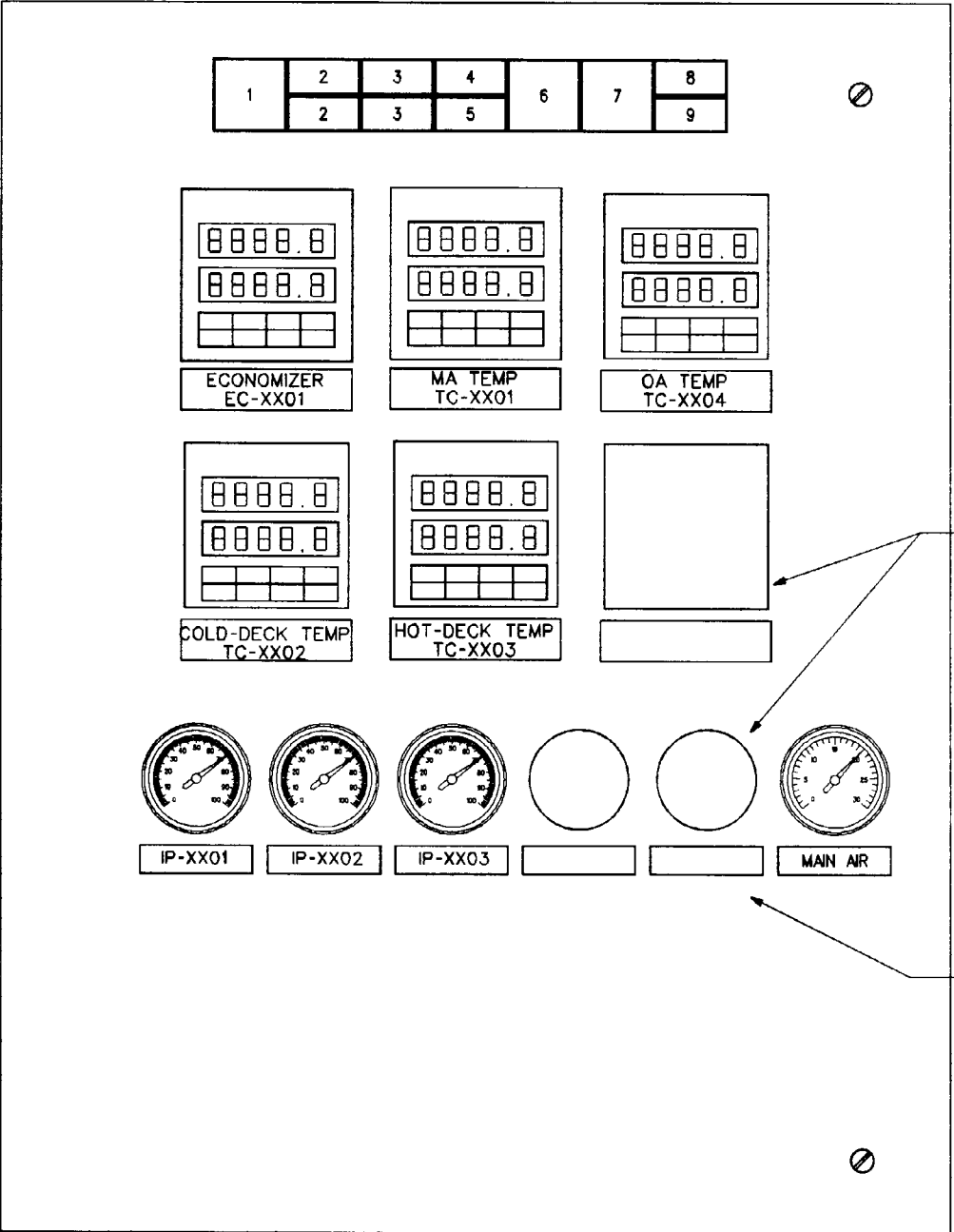
RETURN-FAN STARTER

Figure 4-14B. Control-system ladder diagram for multizone HVAC system XX.

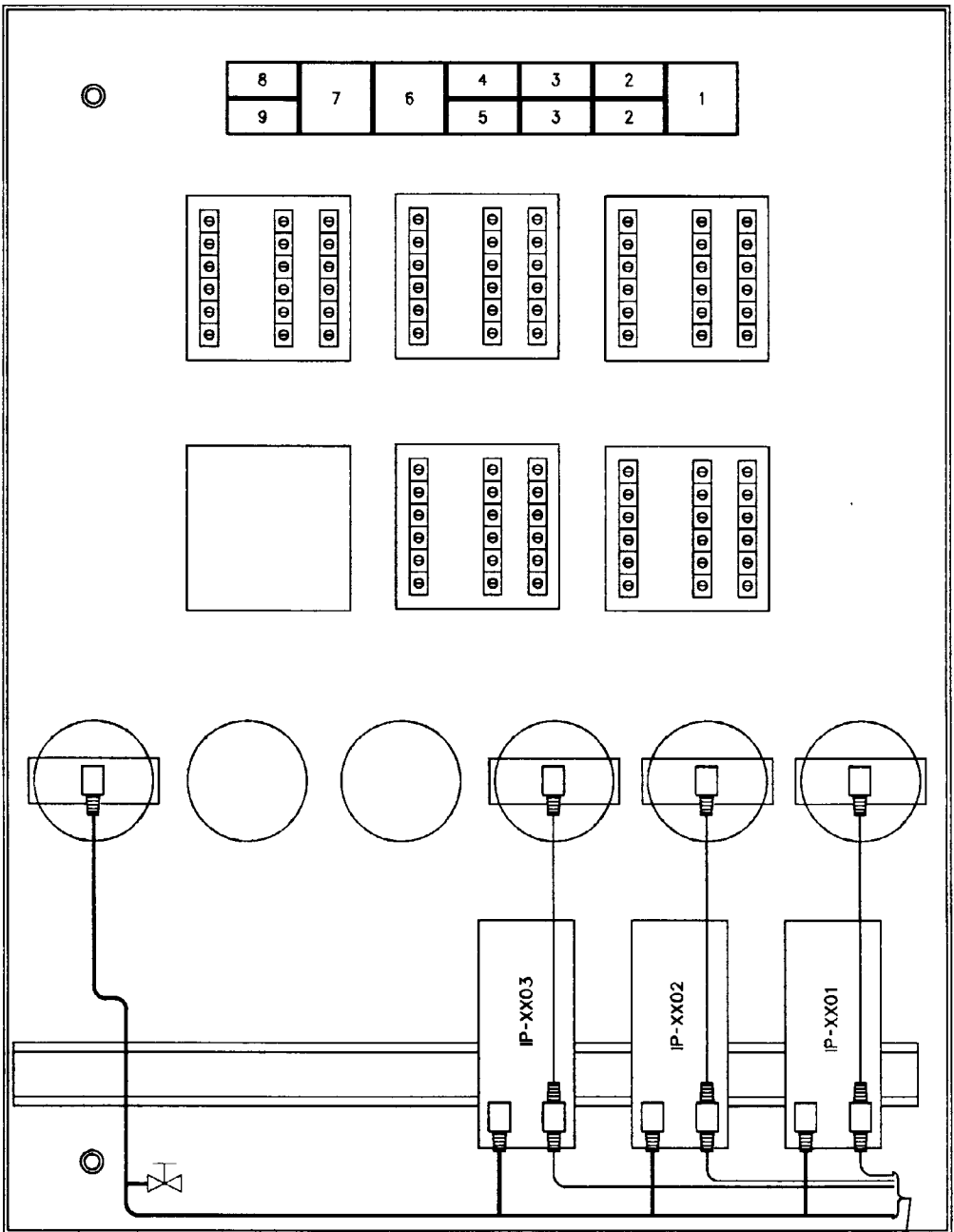
LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
MIXED AIR TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	3-15 PSIG	—
	MPS-XX01	MINIMUM POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM
	TC-XX01	MIXED AIR TEMPERATURE CONTROLLER	55°F	40 TO 140°F	—
	TT-XX01	MIXED AIR TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
	TT-XX02	OUTSIDE AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	TT-XX03	RETURN AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	EC-XX01	ECONOMIZER CONTROLLER	PV CONTACT CLOSE AT 73°F OPEN AT 71°F	-30 TO +130°F	DEV CONTACT CLOSE WHEN ΔT=8 °F OPEN WHEN ΔT=6 °F
	TSL-XX01	LOW TEMPERATURE PROTECTION THERMOSTAT	35°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE TEMPERATURE THERMOSTAT	55°F	5° F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
COLD DECK AIR TEMPERATURE	VLV-XX01	COOLING COIL VALVE	—	3-15 PSIG	CV-20 CLOSE AGAINST 20 PSIG
	TC-XX02	COLD DECK TEMPERATURE CONTROLLER	57°F	40 TO 140°F	—
	TT-XX04	COLD DECK TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
HOT DECK AIR TEMPERATURE	VLV-XX02	HEATING COIL VALVE	—	3-15 PSIG	CV-12 CLOSE AGAINST 16 PSIG
	TC-XX03	HOT DECK TEMPERATURE CONTROLLER	OA TEMP=0°F, SET:120°F OA TEMP=60°F, SET:90°F	40 TO 140°F	—
	TC-XX04	OUTSIDE AIR TEMPERATURE CONTROLLER	60°F PROPORTIONAL BAND=125%	-30 TO 130°F	MINIMUM OUTPUT=50% MAXIMUM OUTPUT=80%
	TT-XX05	HOT DECK TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
OCCUPIED MODE	CLK-XX01 CONTACT	365 DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M,T,W,TH,F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION DELAY MODE	CLK-XX01 CONTACT	365 DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M,T,W,TH,F	

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS, AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 4-14C. Equipment for multizone HVAC control system XX.



(FRONT VIEW)



(REAR VIEW)

TO BULKHEAD FITTINGS

SWITCH AND PILOT LIGHT LEGEND

POSITION LEGEND

- 1 - RESET
- 2 - AUTO/AUTO OVERRIDE
- 3 - ENABLE/OFF
- 4 - LOW TEMP
- 5 - SMOKE

DEVICE TYPE

- NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH
- ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES
- ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES
- PILOT LIGHT
- PILOT LIGHT

IDENTIFIER

- HS-XX02
- HS-XX01
- HS-XX03
- PL-XX05
- PL-XX06

POSITION LEGEND

- 6 - FILTER
- 7 - OCC
- 8 - VENT DELAY
- 9 - ECON

DEVICE TYPE

- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT

IDENTIFIER

- PL-XX04
- PL-XX01
- PL-XX02
- PL-XX03

Figure 4-14D. Control-panel interior-door layout for multizone HVAC system XX.

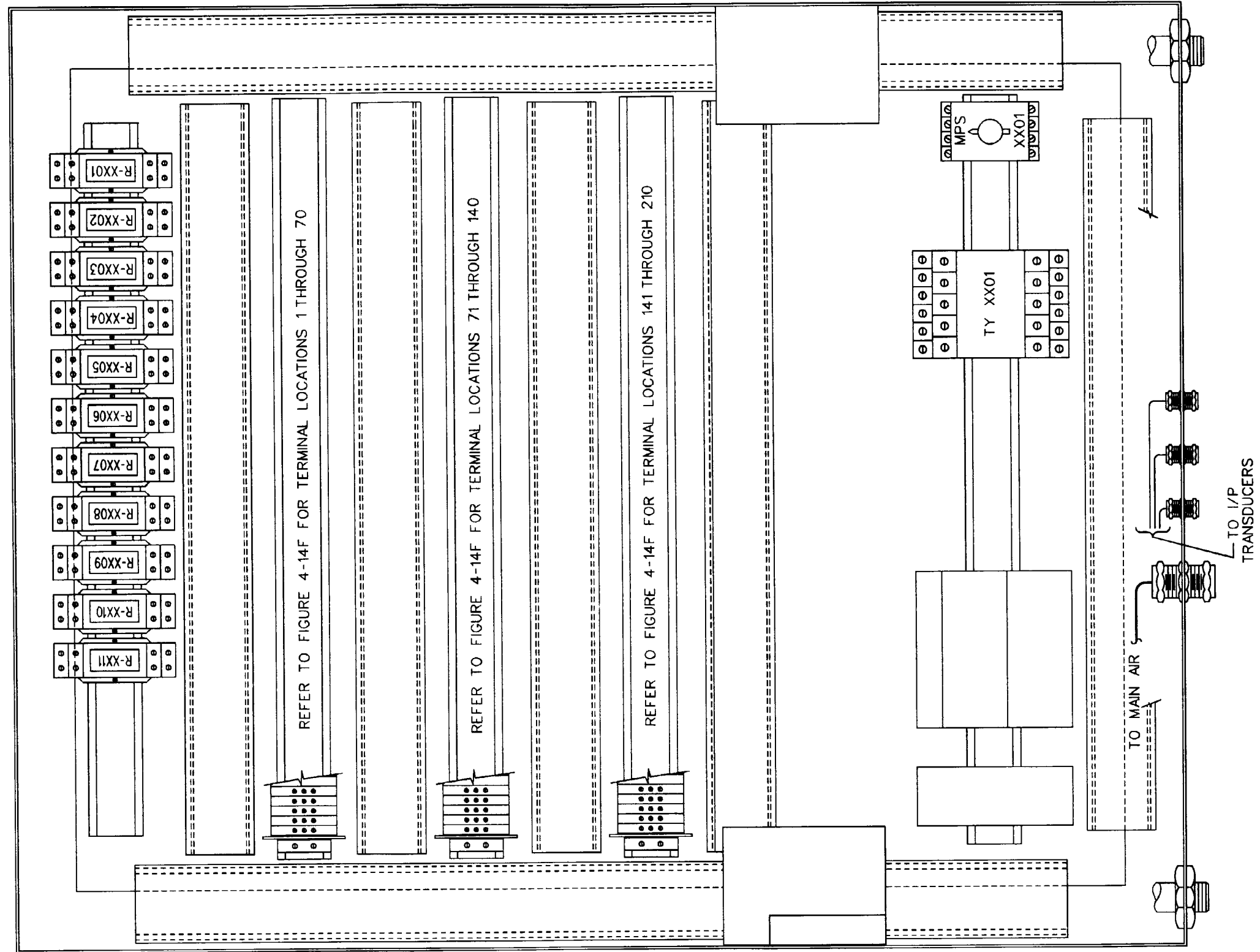


Figure 4-14E. Back-panel layout for multizone HVAC system XX control panel.

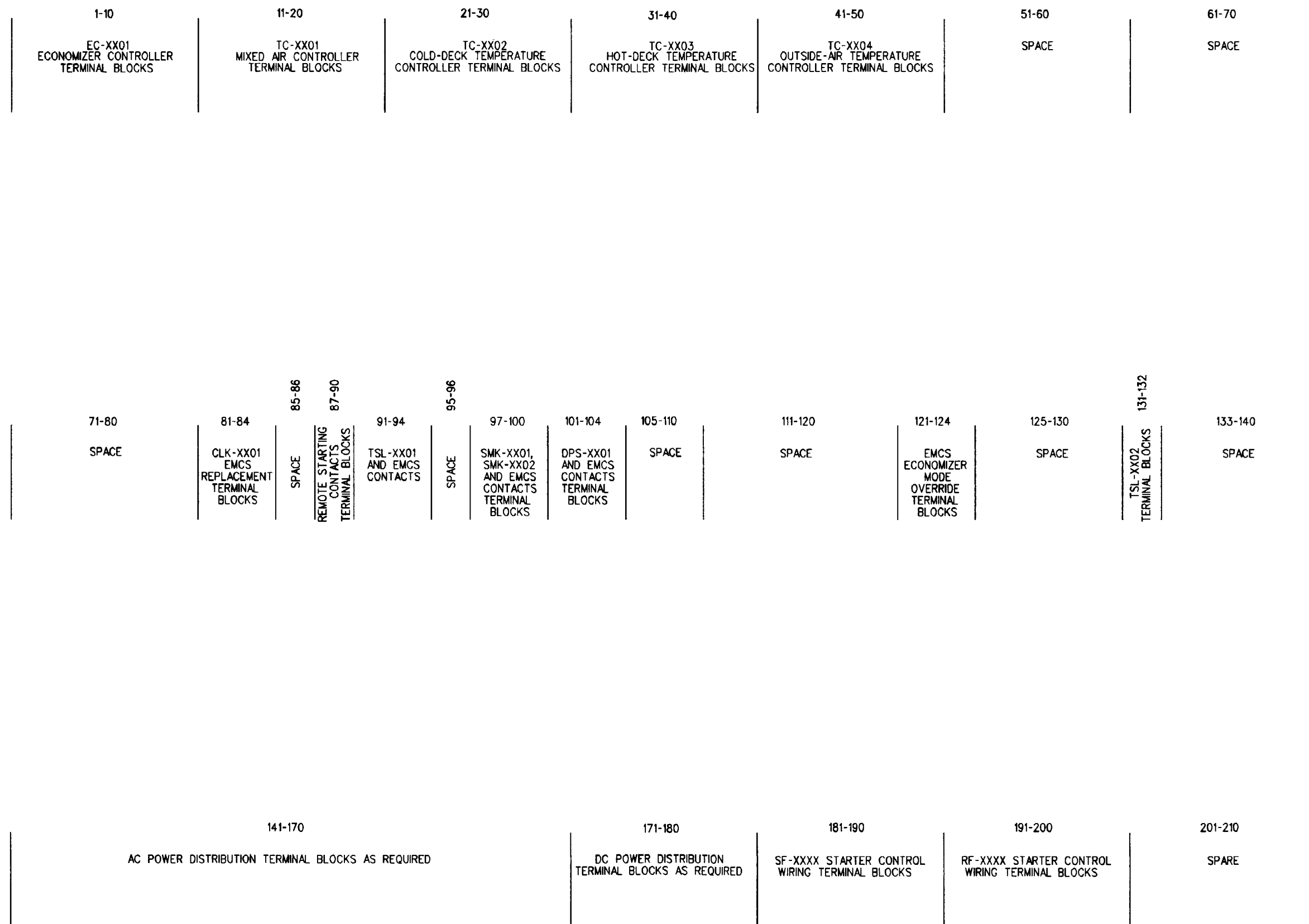


Figure 4-14F. Terminal-block layout for multizone HVAC system XX control panel.

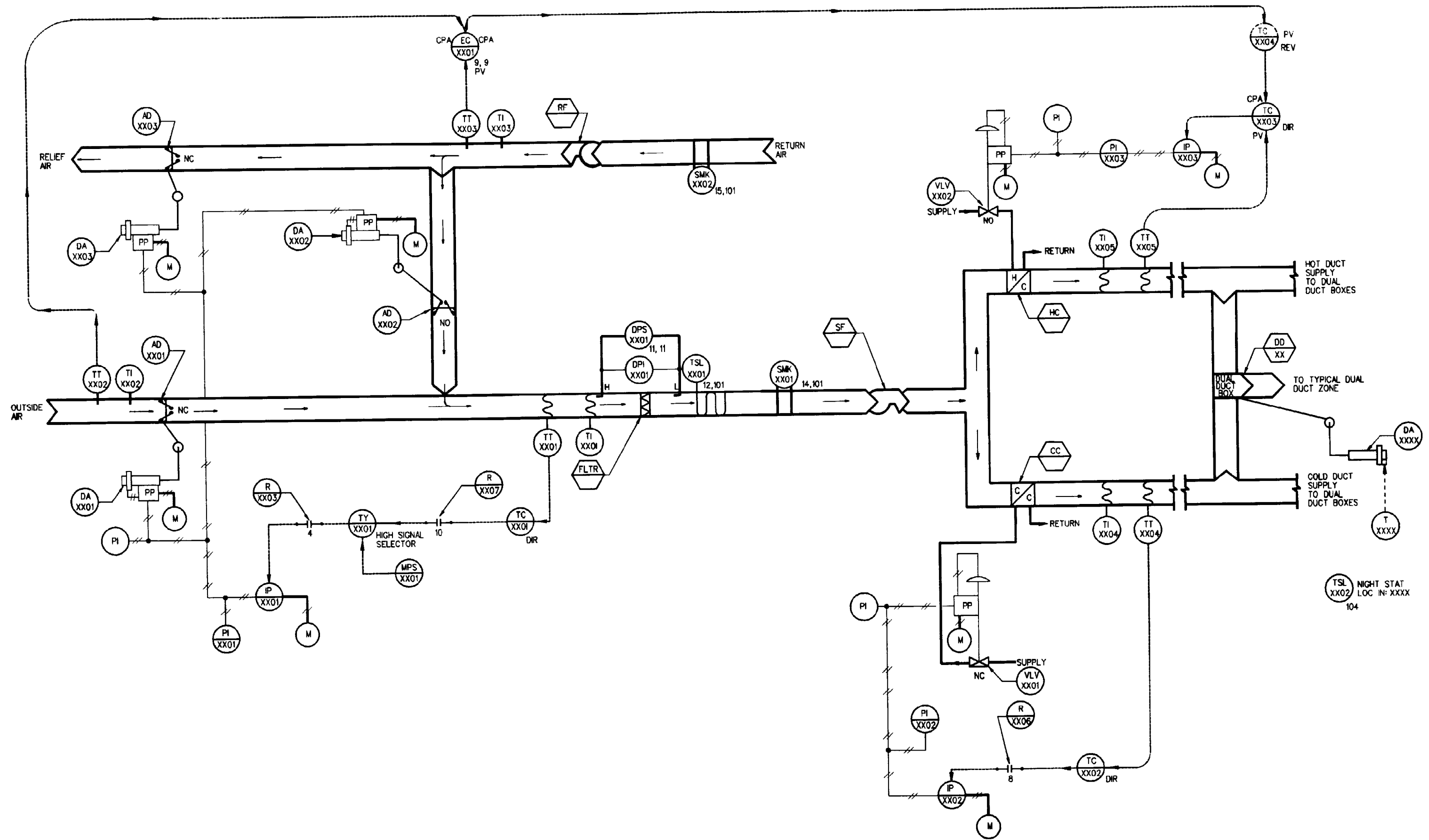


Figure 4-15A. Control-system schematic for dual-duct HVAC system XX.

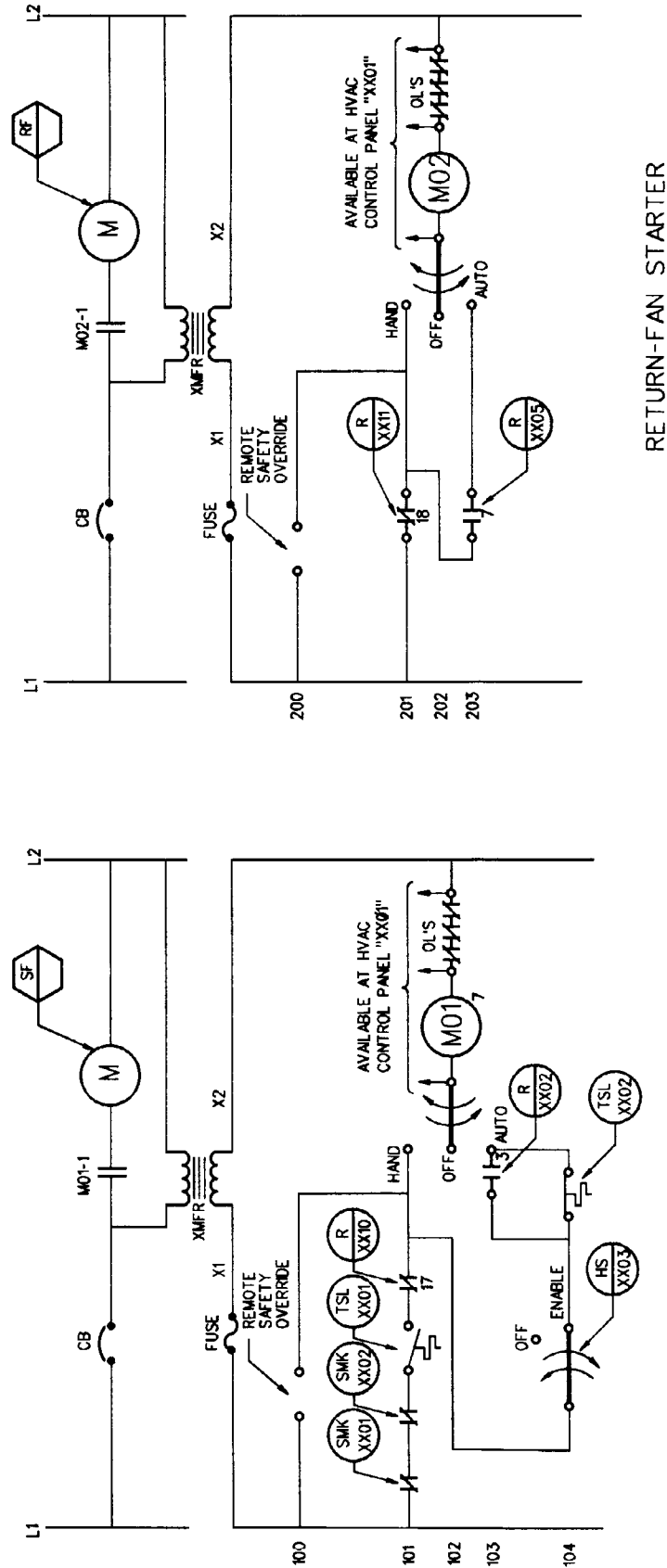
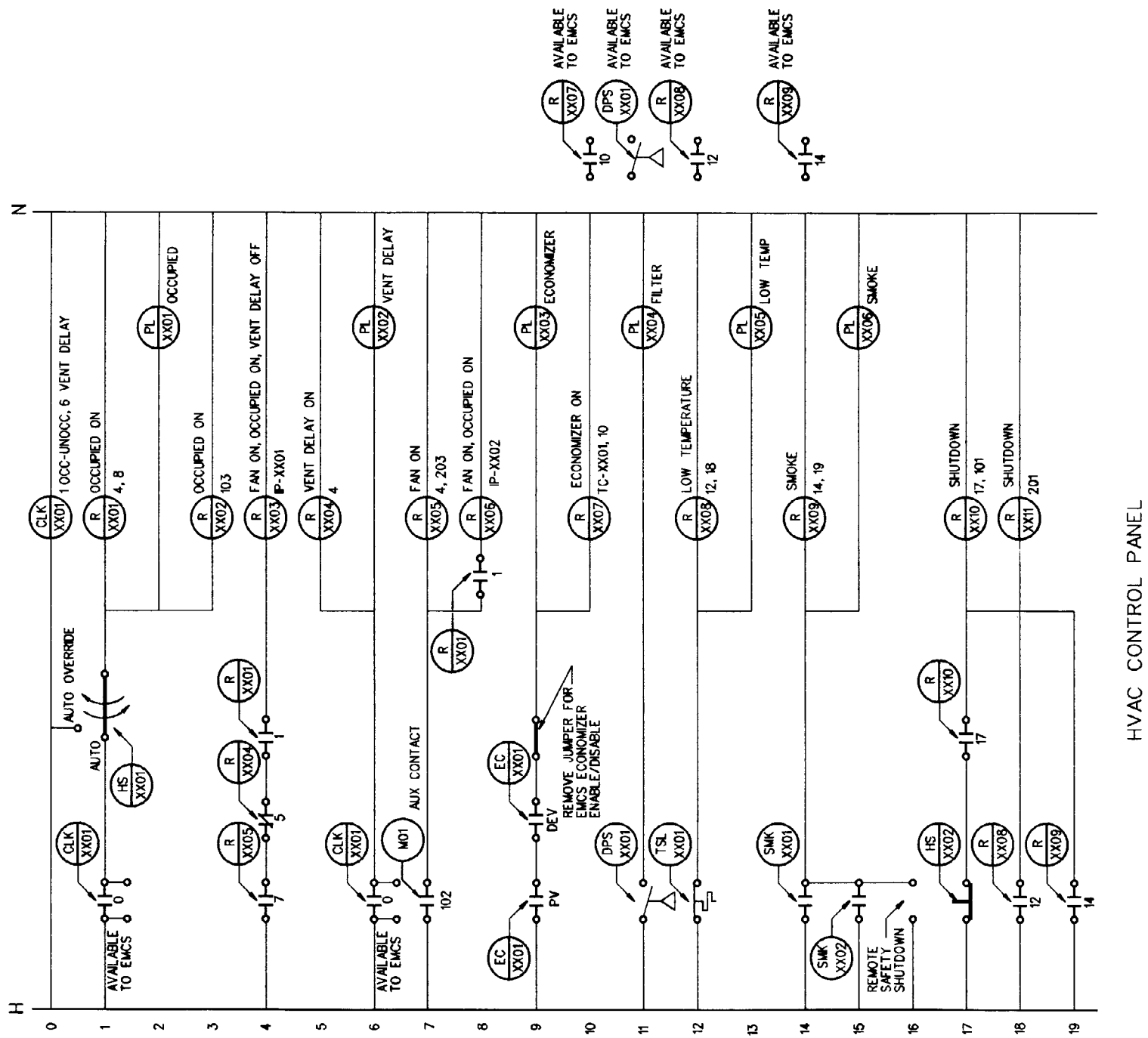
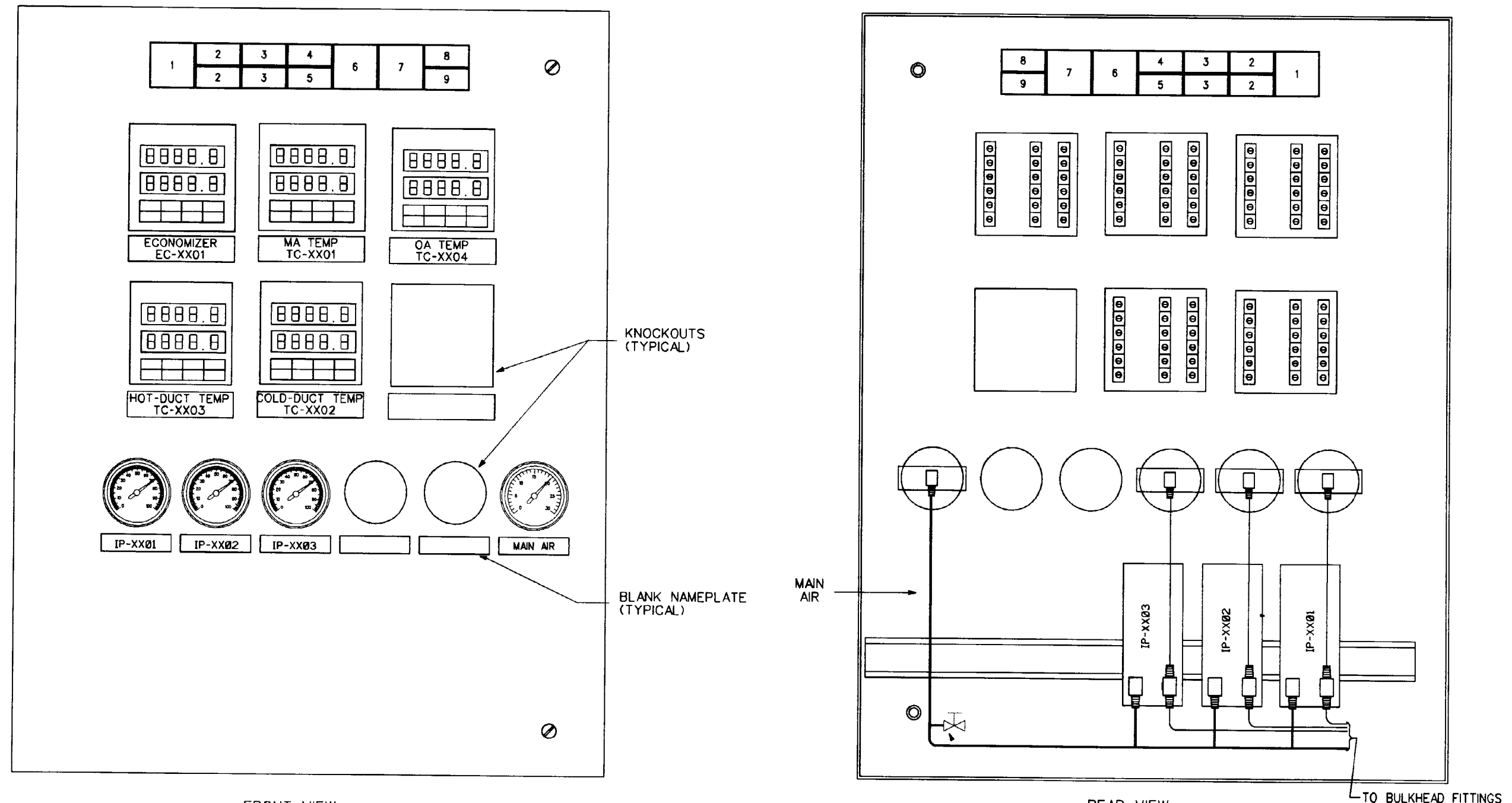


Figure 4-15B. Control-system ladder diagram for dual-duct HVAC system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
MIXED AIR TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	3-15 PSIG	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM
	TC-XX01	MIXED-AIR TEMPERATURE CONTROLLER	55°F	40 TO 140°F	—
	TT-XX01	MIXED-AIR TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
	TT-XX02	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130 °F	—
	TT-XX03	RETURN-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130 °F	—
	EC-XX01	ECONOMIZER CONTROLLER	PV CONTACT CLOSE AT 73°F OPEN AT 71°F	-30 TO +130 °F	DEV CONTACT CLOSE WHEN ΔT=8 °F OPEN WHEN ΔT=6 °F
	TSL-XX01	LOW-TEMPERATURE-PROTECTION THERMOSTAT	35°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
COLD DUCT AIR TEMPERATURE	VLV-XX01	COOLING-COIL VALVE	—	3-15 PSIG	CV=20 CLOSE AGAINST 20 PSIG
	TC-XX02	COLD-DUCT TEMPERATURE CONTROLLER	57°F	40 TO 140°F	—
	TT-XX04	COLD-DUCT TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
HOT DUCT AIR TEMPERATURE	VLV-XX02	HEATING-COIL VALVE	—	3-15 PSIG	CV=12 CLOSE AGAINST 15 PSIG
	TC-XX03	HOT-DUCT TEMPERATURE CONTROLLER	OA TEMP=0°F, SET:120°F OA TEMP=60°F, SET:90°F	40 TO 140°F	—
	TC-XX04	OUTSIDE-AIR TEMPERATURE CONTROLLER	60% PROPORTIONAL BAND=125%	-30 TO 130°F	MINIMUM OUTPUT=50% MAXIMUM OUTPUT=80%
	TT-XX05	HOT-DUCT TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M,T,W,TH,F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M,T,W,TH,F	

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS, AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 4-15C. Equipment for dual-duct HVAC control system XX.



POSITION LEGEND

- 1 - RESET
- 2 - AUTO/AUTO OVERRIDE
- 3 - ENABLE/OFF
- 4 - LOW TEMP
- 5 - SMOKE

DEVICE TYPE

- NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH
- ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES
- ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES
- PILOT LIGHT
- PILOT LIGHT

IDENTIFIER

- HS-XX02
- HS-XX01
- HS-XX03
- PL-XX05
- PL-XX06

SWITCH AND PILOT LIGHT LEGEND

POSITION LEGEND

- 6 - FILTER
- 7 - OCC
- 8 - VENT DELAY
- 9 - ECON

DEVICE TYPE

- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT

IDENTIFIER

- PL-XX04
- PL-XX01
- PL-XX02
- PL-XX03

Figure 4-15D. Control-panel interior-door layout for dual-duct HVAC system XX.

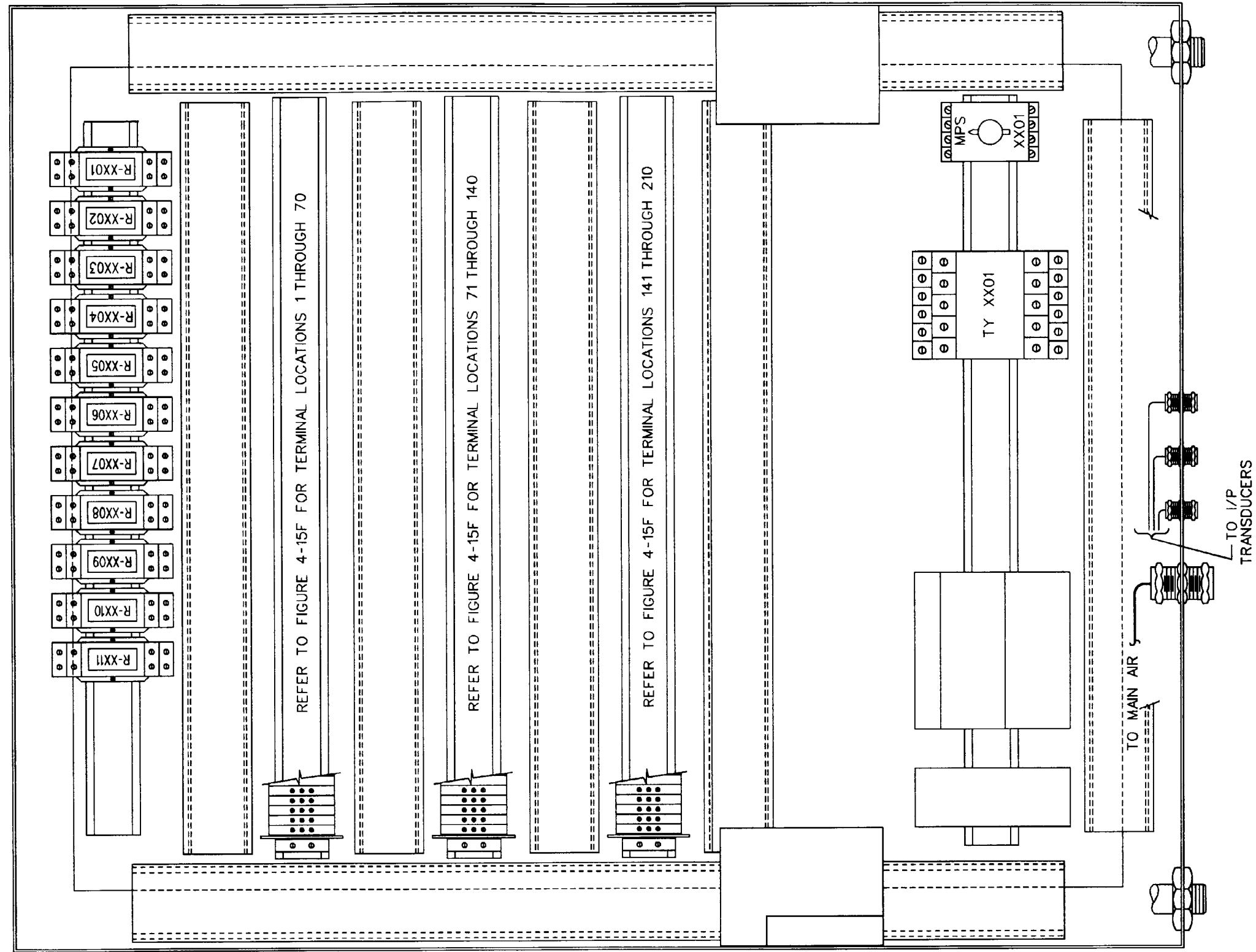


Figure 4-15E. Back-panel layout for dual-duct HVAC system XX control panel.

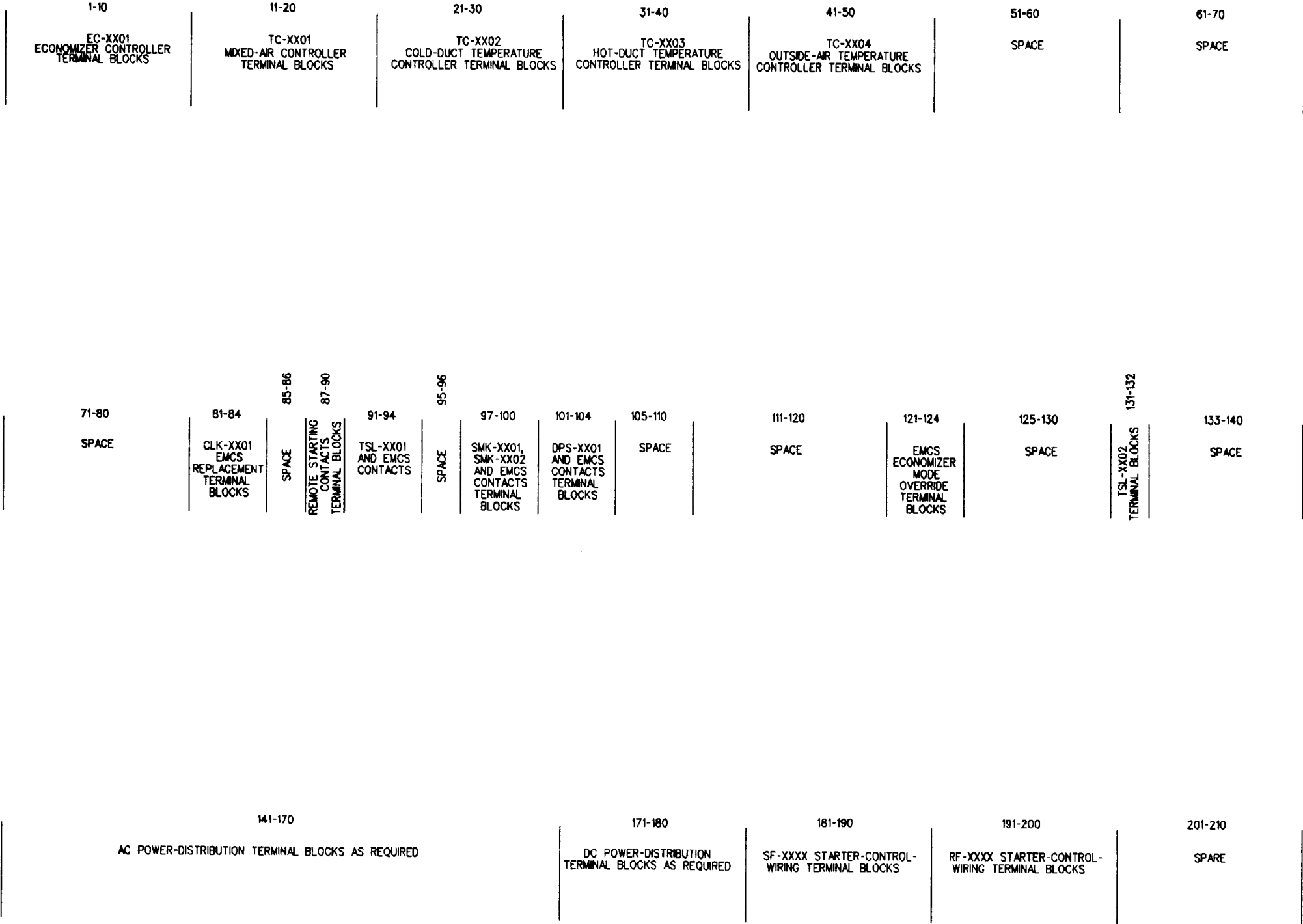


Figure 4-15F. Terminal-block layout for dual-duct HVAC system XX control panel.

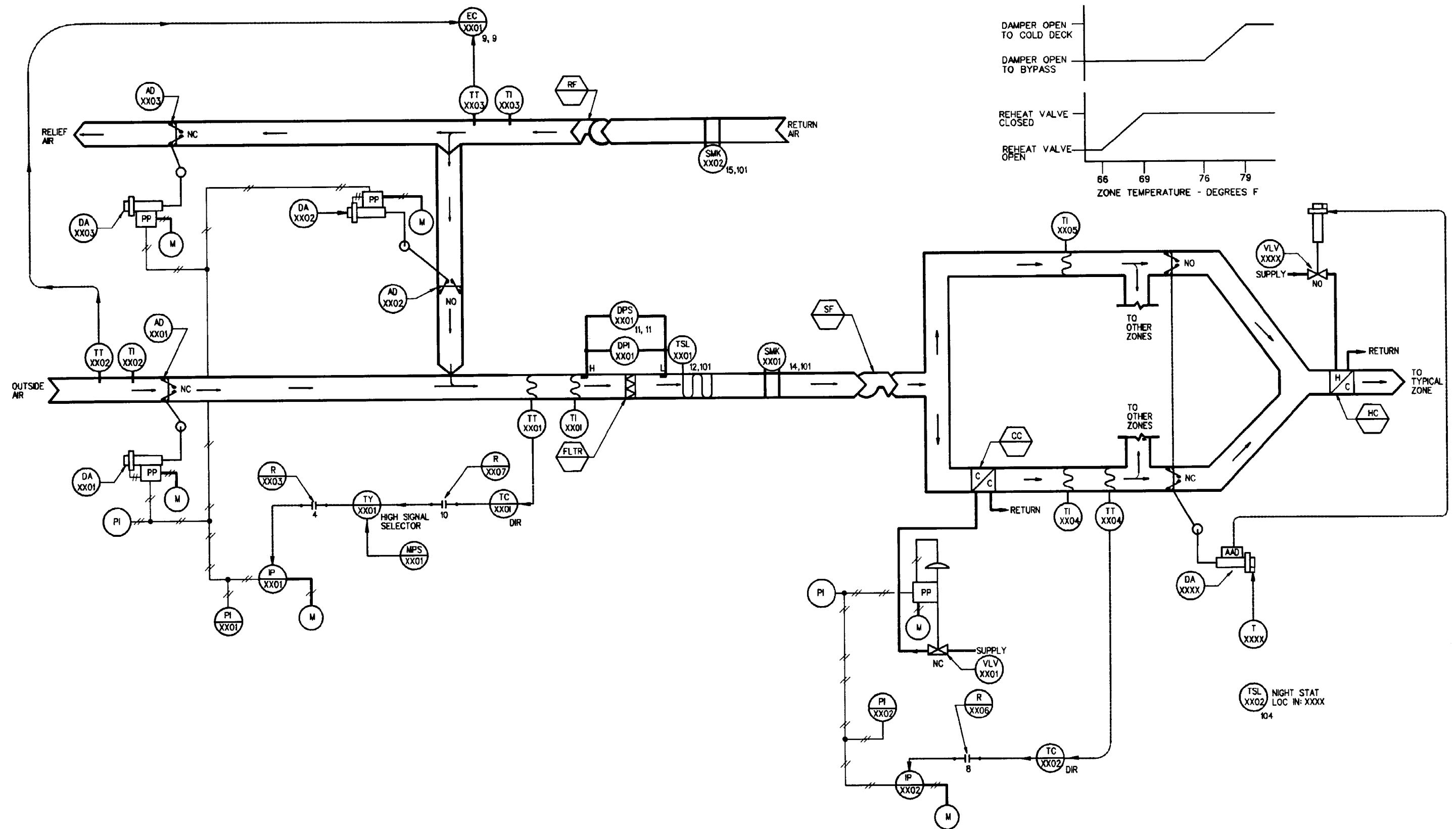
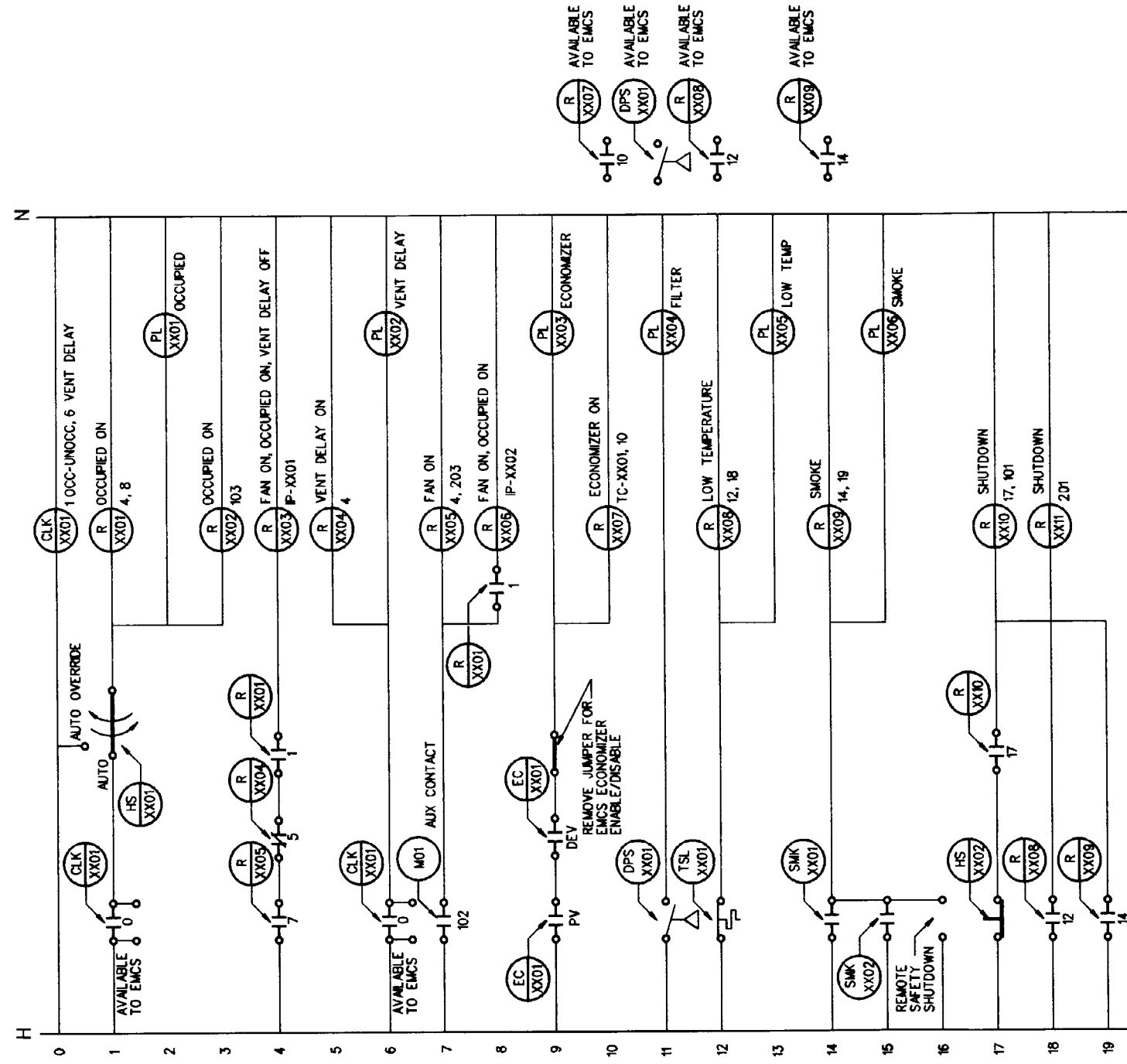


Figure 4-16A. Control-system schematic for bypass multizone HVAC system XX.



HVAC CONTROL PANEL

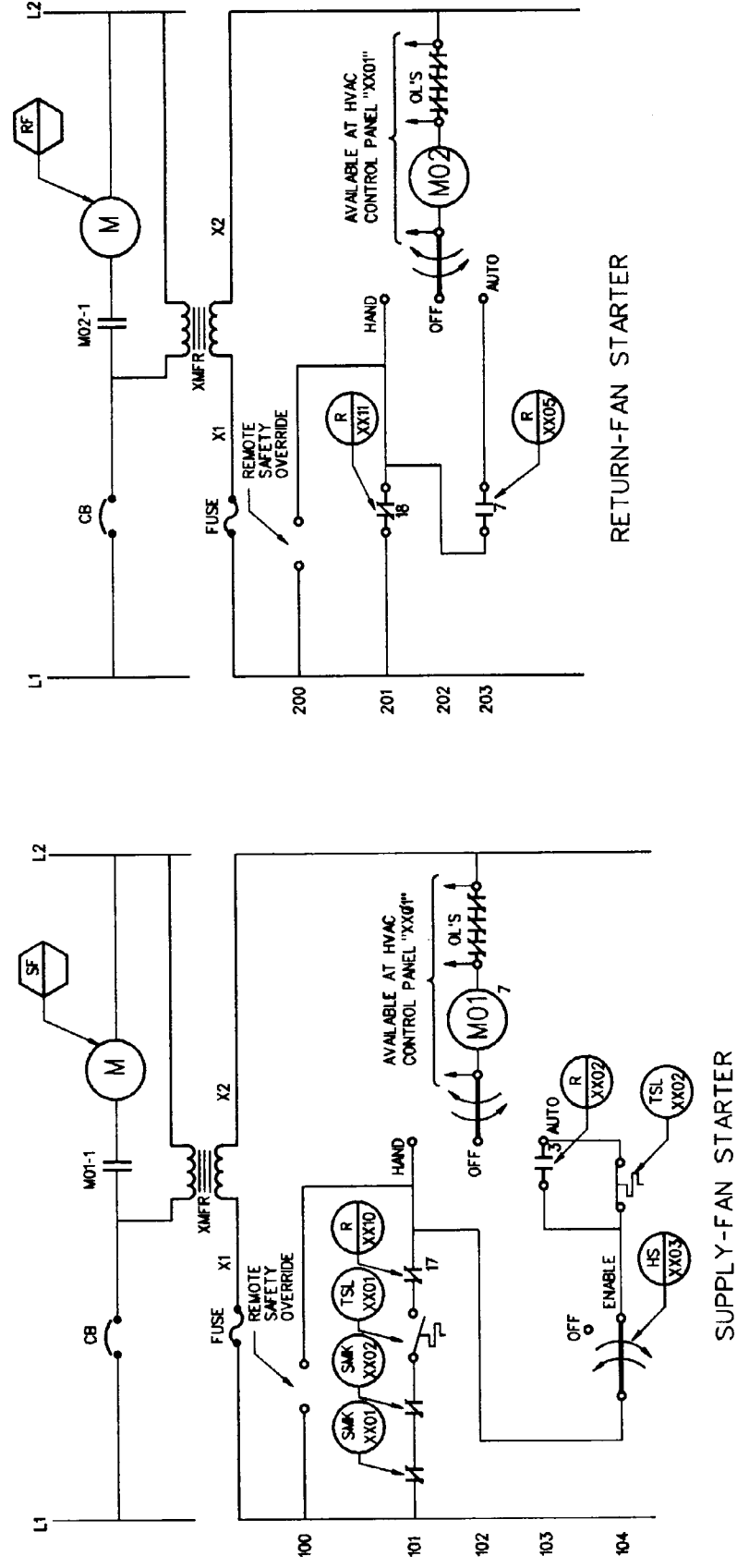
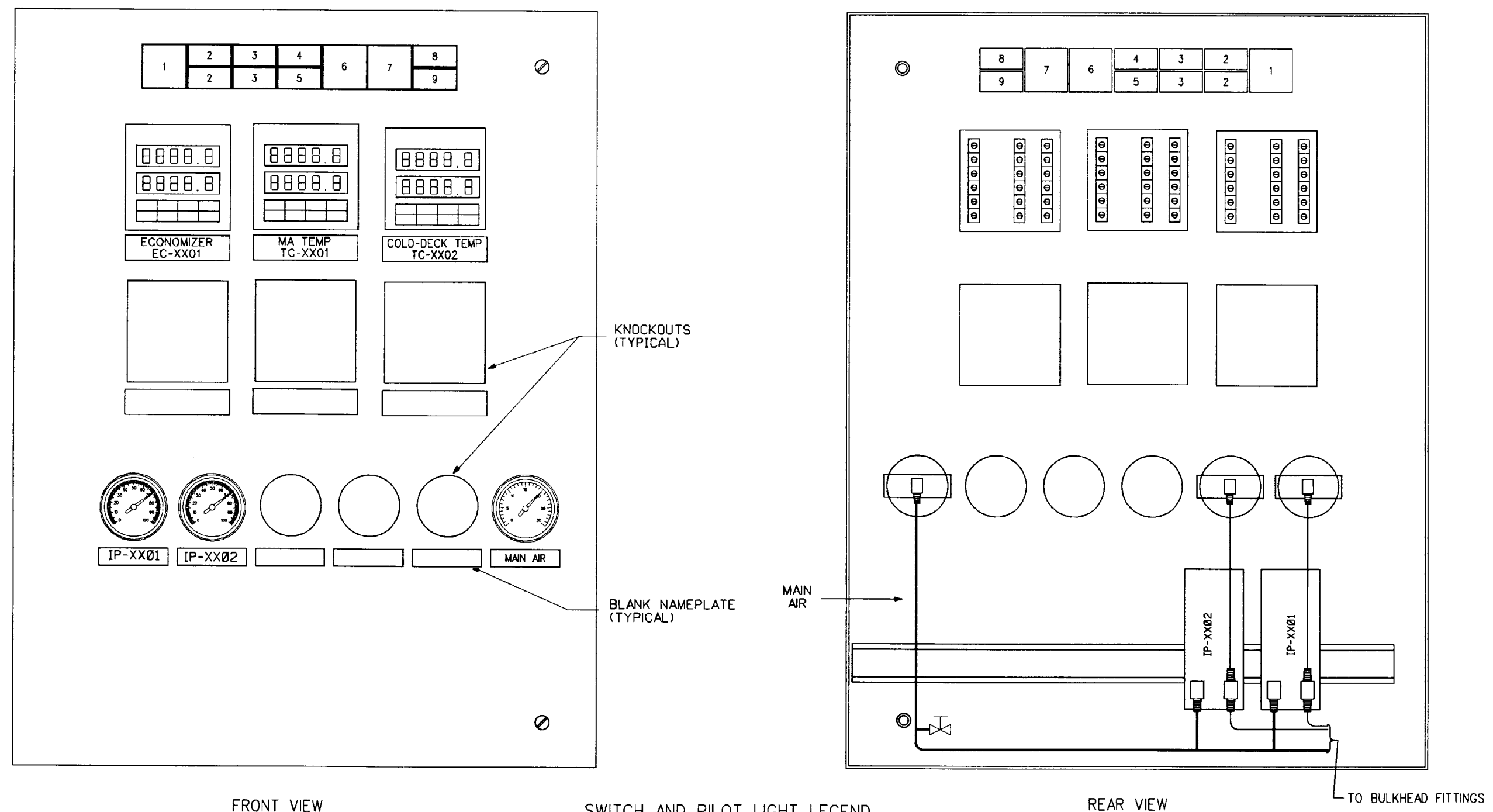


Figure 4-16B. Control-system ladder diagram for bypass multizone HVAC system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
MIXED-AIR TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	3-15 PSIG	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM
	TC-XX01	MIXED-AIR TEMPERATURE CONTROLLER	55°F	40 TO 140°F	—
	TT-XX01	MIXED-AIR TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
	TT-XX02	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130 °F	—
	TT-XX03	RETURN-AIR TEMPERATURE TRANSMITTER	—	-30 TO +140 °F	—
	EC-XX01	ECONOMIZER CONTROLLER	PV CONTACT CLOSE AT 73°F OPEN AT 71°F	-30 TO +140 °F	DEV CONTACT CLOSE WHEN ΔT=8 °F OPEN WHEN ΔT=6 °F
	TSL-XX01	LOW-TEMPERATURE PROTECTION THERMOSTAT	35°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
COLD-DECK AIR TEMPERATURE	VLV-XX01	COOLING-COIL VALVE	—	3-15 PSIG	CV-20 CLOSE AGAINST 20 PSIG
	TC-XX02	COLD-DECK TEMPERATURE CONTROLLER	57°F	40 TO 140°F	—
	TT-XX04	COLD-DECK TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
SPACE XXXX	VLV-XXXX	ZONE-HEATING COIL VALVE	—	0 TO 40% OF THERMOSTAT OUTPUT	CV-7 CLOSE AGAINST 16 PSIG
	DA-XXXX	ZONE-DAMPER ACTUATOR	—	60 TO 100% OF THERMOSTAT OUTPUT	—
	T-XXXX	ZONE THERMOSTAT	68° F - HEATING 74° F - COOLING	—	—
SPACE ZZZZ	VLV-ZZZZ	ZONE-HEATING COIL VALVE	—	0 TO 40% OF THERMOSTAT OUTPUT	CV-2 CLOSE AGAINST 16 PSIG
	DA-ZZZZ	ZONE-DAMPER ACTUATOR	—	60 TO 100% OF THERMOSTAT OUTPUT	—
	T-ZZZZ	ZONE THERMOSTAT	68° F - HEATING 74° F - COOLING	—	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M,T,W,TH,F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M,T,W,TH,F	

Figure 4-16C. Equipment for bypass multizone HVAC control system XX.



POSITION LEGEND	DEVICE TYPE	IDENTIFIER
1 - RESET	NON-ILLUMINATED MOMENTARY PUSH BUTTON SWITCH	HS-XX02
2 - AUTO/AUTO OVERRIDE	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX01
3 - ENABLE/OFF	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX03
4 - LOW TEMP	PILOT LIGHT	PL-XX05
5 - SMOKE	PILOT LIGHT	PL-XX06

SWITCH AND PILOT LIGHT LEGEND

POSITION LEGEND	DEVICE TYPE	IDENTIFIER
6 - FILTER	PILOT LIGHT	PL-XX04
7 - OCC	PILOT LIGHT	PL-XX01
8 - VENT DELAY	PILOT LIGHT	PL-XX02
9 - ECON	PILOT LIGHT	PL-XX03

Figure 4-16D. Control-panel interior-door layout for bypass multizone HVAC control system XX.

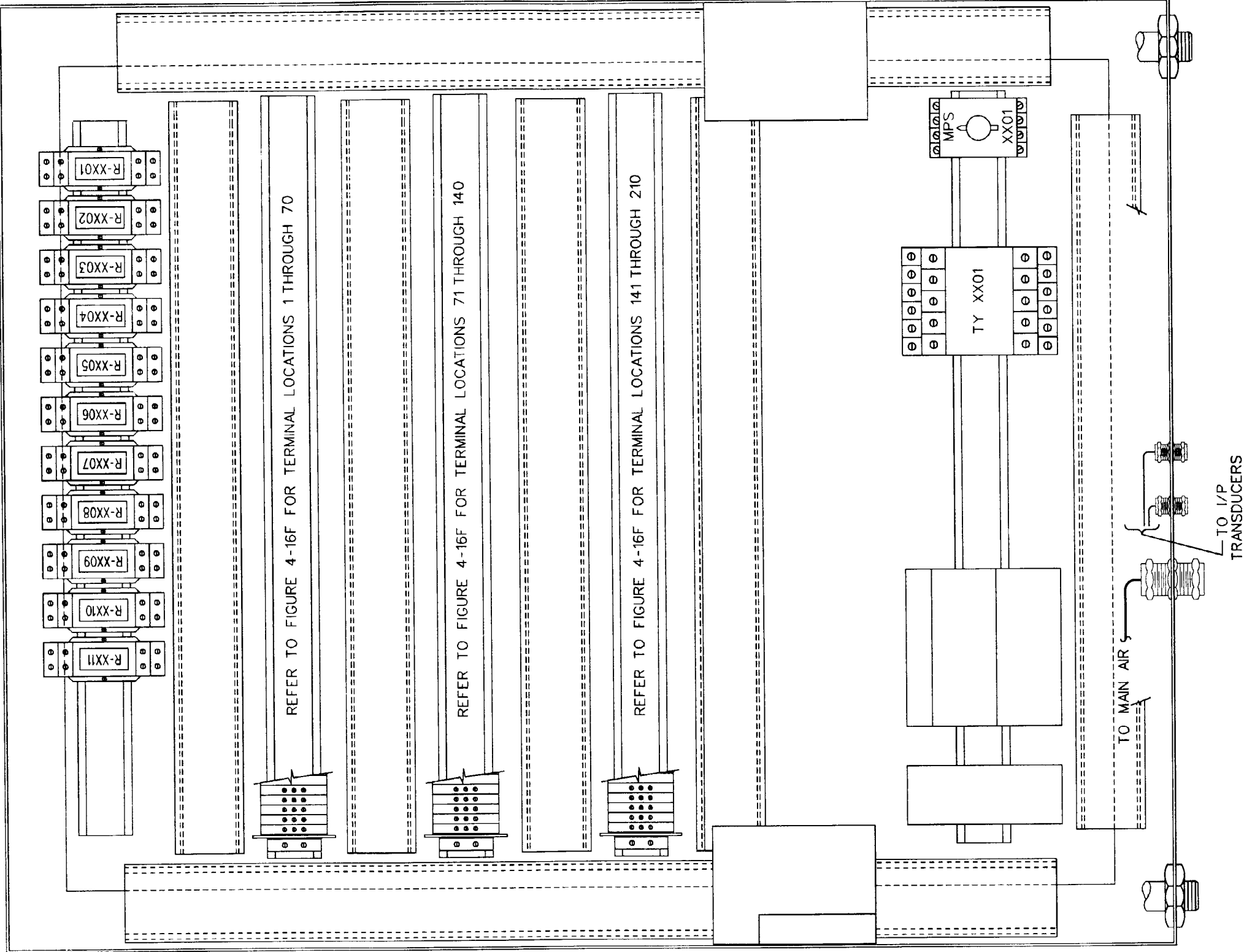


Figure 4-16E. Back-panel layout for bypass multizone HVAC control system XX control panel.

1-10 EC-XX01 ECONOMIZER-CONTROLLER TERMINAL BLOCKS	11-20 TC-XX01 MIXED-AIR CONTROLLER TERMINAL BLOCKS	21-30 TC-XX02 COLD DECK TEMPERATURE CONTROLLER TERMINAL BLOCKS	31-40 SPACE	41-50 SPACE	51-60 SPACE	61-70 SPACE							
71-80 SPACE	81-84 CLK-XX01 EMCS REPLACEMENT TERMINAL BLOCKS	85-86 SPACE	87-90 REMOTE STARTING CONTACTS TERMINAL BLOCKS	91-94 TSL-XX01 AND EMCS CONTACTS	95-96 SPACE	97-100 SMK-XX01, SMK-XX02 AND EMCS CONTACTS TERMINAL BLOCKS	101-104 DPS-XX01 AND EMCS CONTACTS TERMINAL BLOCKS	105-110 SPACE	111-120 SPACE	121-124 EMCS ECONOMIZER MODE OVERRIDE TERMINAL BLOCKS	125-130 SPACE	131-132 TSL-XX02 TERMINAL BLOCKS	133-140 SPACE
141-170 AC POWER-DISTRIBUTION TERMINAL BLOCKS AS REQUIRED				171-180 DC POWER-DISTRIBUTION TERMINAL BLOCKS AS REQUIRED		181-190 SF-XXXX STARTER-CONTROL WIRING TERMINAL BLOCKS		191-200 RF-XXXX STARTER-CONTROL WIRING TERMINAL BLOCKS		201-210 SPARE			

Figure 4-16F. Terminal-block layout for bypass multizone HVAC control system XX control panel.

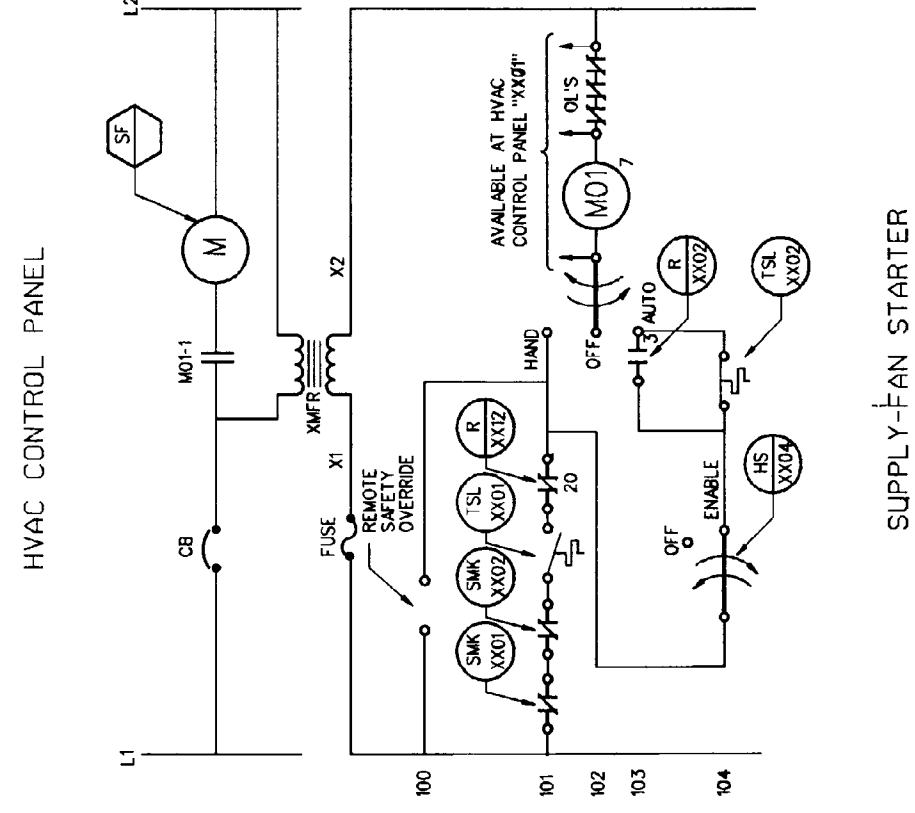
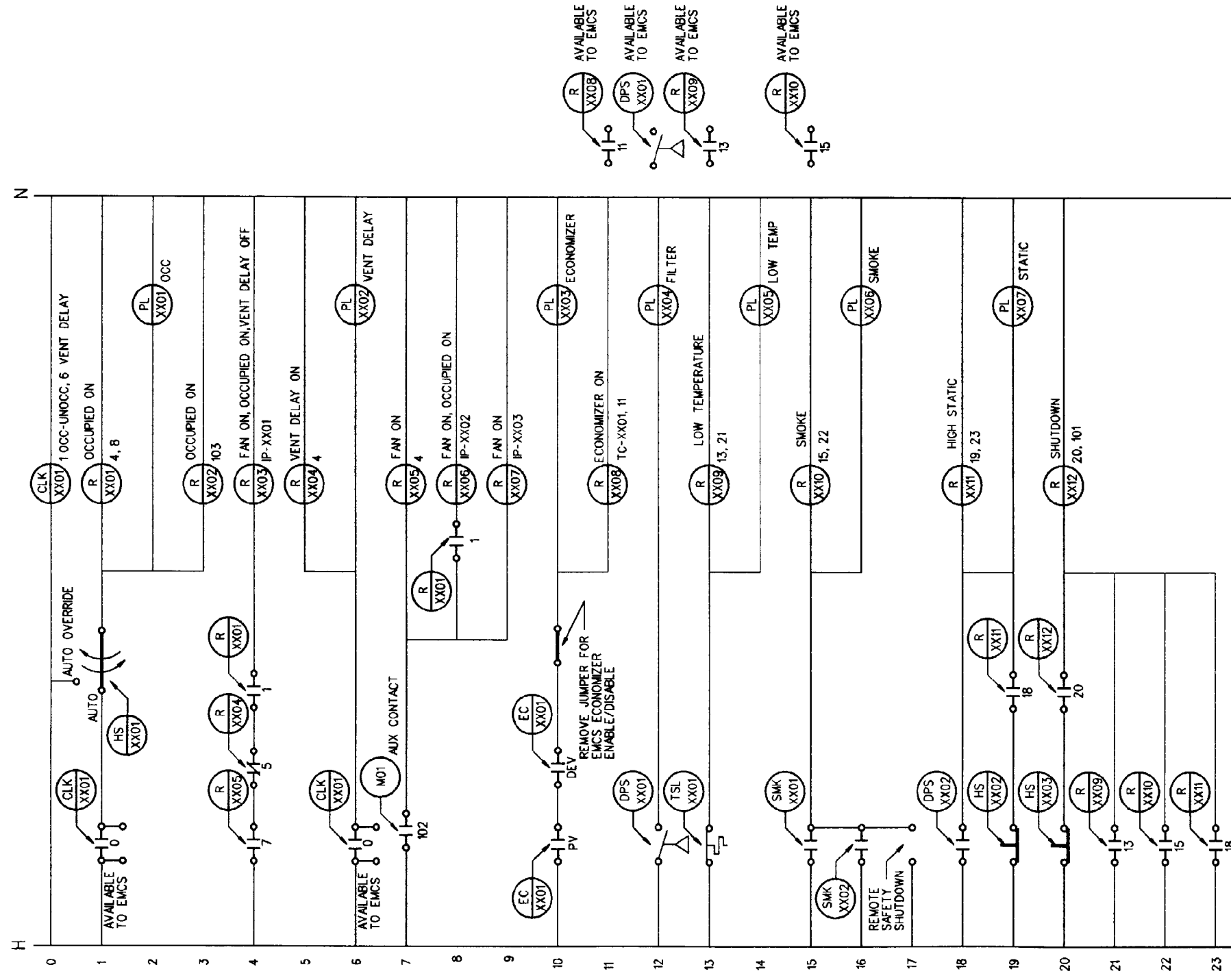
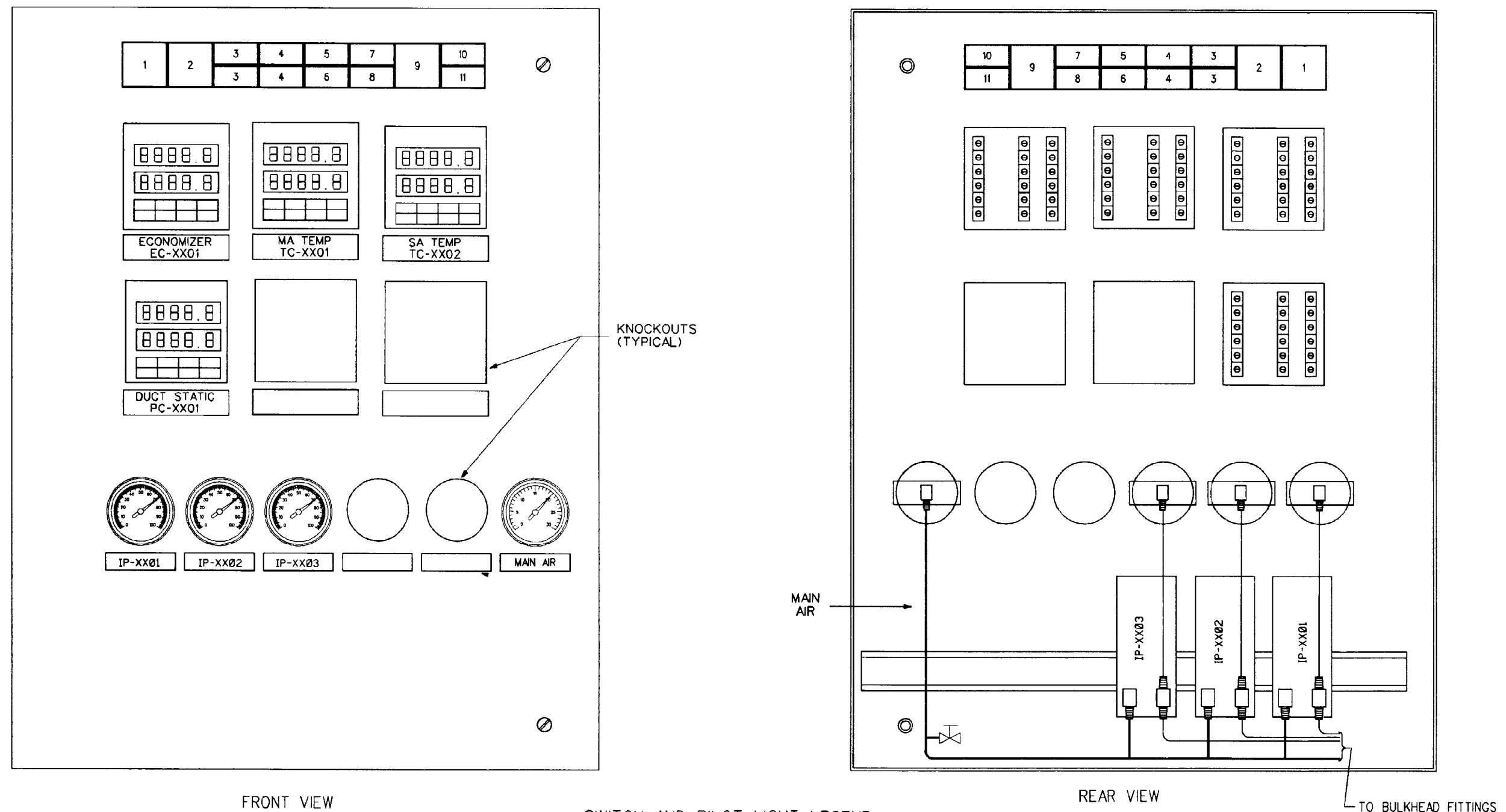


Figure 4-17B. Control-system ladder diagram for VAV HVAC system XX without return fan.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
MIXED-AIR TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	3-15 PSIG	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM AT MAXIMUM SUPPLY FAN TURN DOWN
	TC-XX01	MIXED-AIR TEMPERATURE CONTROLLER	55°F	40° TO 140°F	—
	TT-XX01	MIXED-AIR TEMPERATURE TRANSMITTER	—	40° TO 140°F	—
	TT-XX02	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130 °F	—
	TT-XX03	RETURN-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130 °F	—
	EC-XX01	ECONOMIZER CONTROLLER	PV CONTACT CLOSE AT 73°F OPEN AT 71°F	-30 TO +130 °F	DEV CONTACT CLOSE WHEN ΔT=8 °F OPEN WHEN ΔT=6 °F
	TSL-XX01	LOW-TEMPERATURE PROTECTION THERMOSTAT	35°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5° F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
DISCHARGE-AIR TEMPERATURE	VLV-XX01	COOLING-COIL VALVE	—	3-15 PSIG	CV=20 CLOSE AGAINST 20 PSIG
	TC-XX02	FAN-DISCHARGE TEMPERATURE CONTROLLER	57°F	40° TO 140°F	—
	TT-XX04	FAN-DISCHARGE TEMPERATURE TRANSMITTER	—	40° TO 140°F	—
SUPPLY-DUCT STATIC PRESSURE	DA-XX04	SUPPLY-FAN INLET VANE ACTUATOR	—	3-15 PSIG	—
	PC-XX01	SUPPLY-DUCT STATIC PRESSURE CONTROLLER	1.2 INCHES WATER	0.0-2.0 INCHES WATER	—
	DPT-XX01	SUPPLY-DUCT STATIC PRESSURE TRANSMITTER	—	0.0-2.0 INCHES WATER	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M,T,W,TH,F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M,T,W,TH,F	
TERMINAL UNITS	VLV-XXXX	HEATING-COIL VALVE-SPACE XXXY	—	—	CV=0.7 CLOSE AGAINST 10PSIG
	●	●	●	●	●
	VLV-YYYY	HEATING-COIL VALVE-SPACE XXXY	—	—	CV=1.2 CLOSE AGAINST 10PSIG

NOTE: OTHER DEVICES SUCH AS IPS, RELAYS, SIGNAL SELECTORS, AND TERMINAL UNIT CONTROLLERS ARE NOT SHOWN

Figure 4-17C. Equipment for VAV HVAC system XX without return fan.



SWITCH AND PILOT LIGHT LEGEND			SWITCH AND PILOT LIGHT LEGEND		
POSITION LEGEND	DEVICE TYPE	IDENTIFIER	POSITION LEGEND	DEVICE TYPE	IDENTIFIER
1 - RESET	NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH	HS-XX03	6 - SMOKE	PILOT LIGHT	PL-XX06
2 - STATIC RESET	NON-ILLUMINATED MOMENTARY PUSH BUTTON SWITCH	HS-XX02	7 - HIGH STATIC	PILOT LIGHT	PL-XX07
3 - AUTO/AUTO OVERRIDE	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX01	8 - FILTER	PILOT LIGHT	PL-XX04
4 - ENABLE/OFF	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX04	9 - OCC	PILOT LIGHT	PL-XX01
5 - LOW TEMP	PILOT LIGHT	PL-XX05	10 - VENT DELAY	PILOT LIGHT	PL-XX02
			11 - ECON	PILOT LIGHT	PL-XX03

Figure 4-17D. Control-panel interior-door layout for VAV HVAC system XX without return fan.

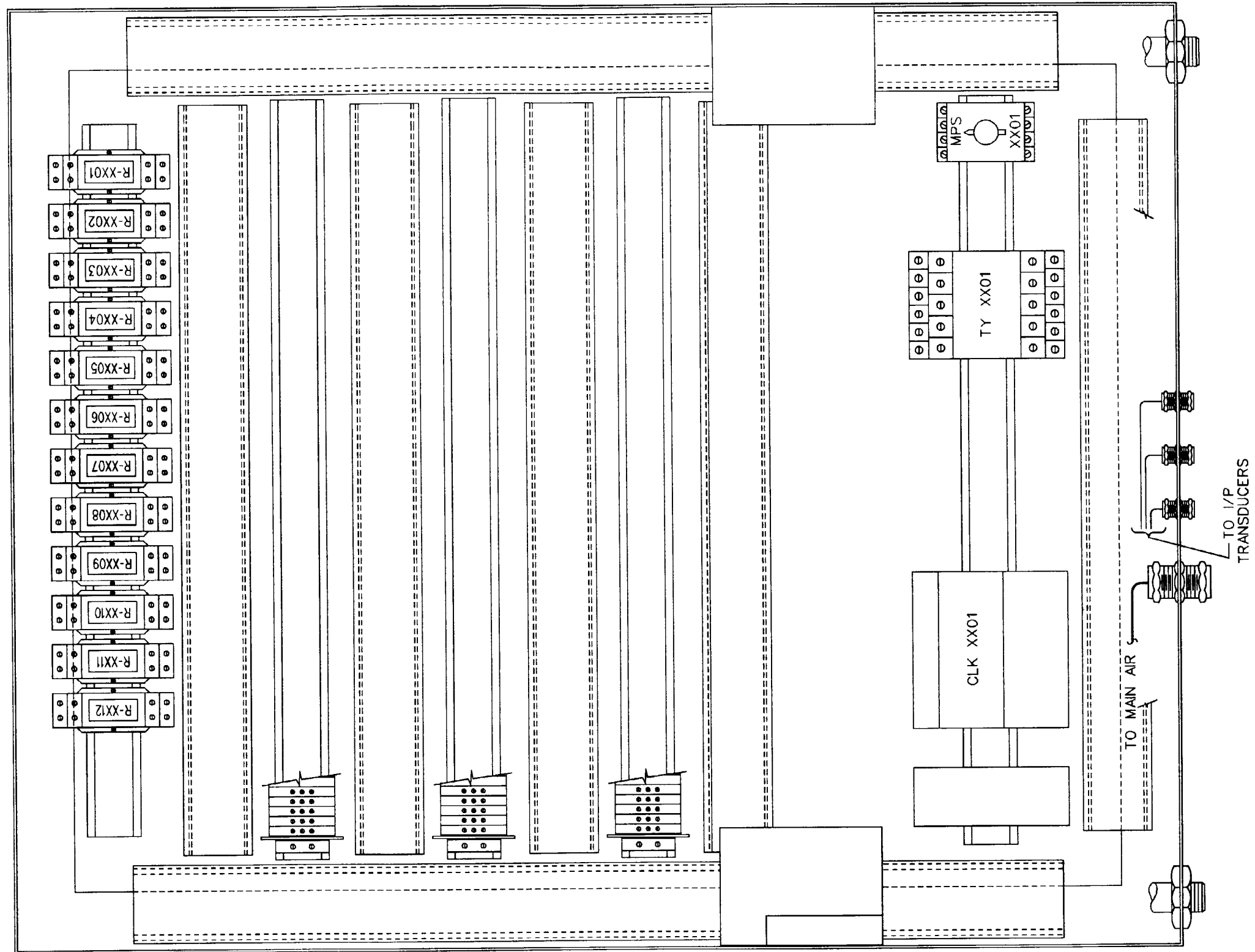
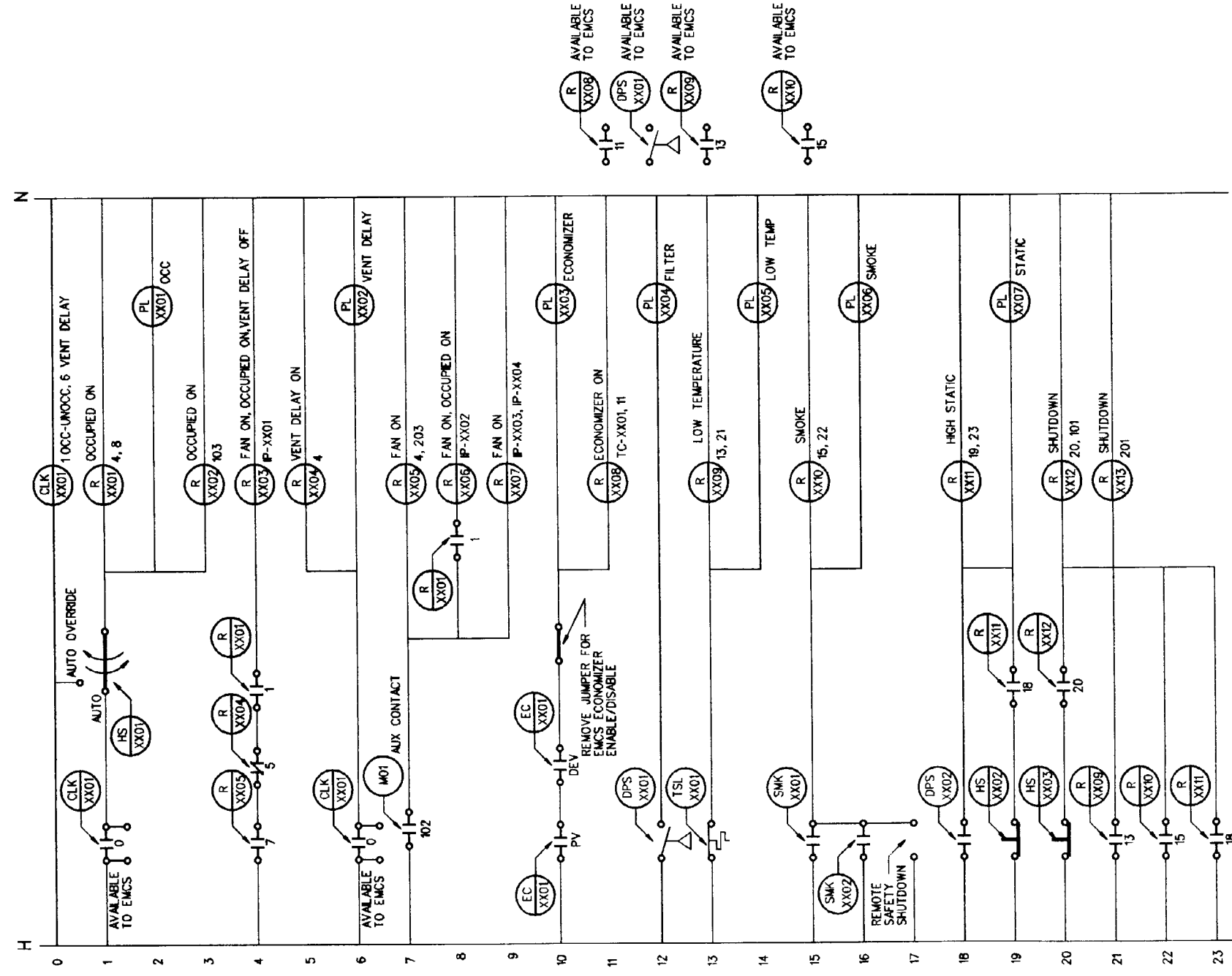


Figure 4-17E. Control-panel back-panel layout for VAV HVAC system XX without return fan.

1-10	11-20	21-30	31-40	41-50	51-60	61-70
EC-XX01 ECONOMIZER-CONTROLLER TERMINAL BLOCKS	TC-XX01 MIXED-AIR CONTROLLER TERMINAL BLOCKS	TC-XX02 SUPPLY-AIR TEMPERATURE CONTROLLER TERMINAL BLOCKS	PC-XX01 SUPPLY-DUCT STATIC-PRESSURE CONTROLLER TERMINAL BLOCKS	SPACE	SPACE	SPACE
71-80	81-84	85-86	87-90	91-94	95-96	97-100
SPACE	CLK-XX01 EMCS REPLACEMENT TERMINAL BLOCKS	SPACE	REMOTE STARTING CONTACTS TERMINAL BLOCKS	TSL-XX01 AND EMCS CONTACTS	SPACE	SMK-XX01, SMK-XX02 AND EMCS CONTACTS TERMINAL BLOCKS
						101-104
						DPS-XX01 AND EMCS CONTACTS TERMINAL BLOCKS
						105-110
						SPACE
						111-112
						DPS-XX02 CONTACTS TERMINAL BLOCKS
						113-120
						SPACE
						121-124
						EMCS ECONOMIZER MODE OVERRIDE TERMINAL BLOCKS
						125-130
						SPACE
						131-132
						TSL-XX02 TERMINAL BLOCKS
						133-140
						SPACE
141-170				171-180		181-190
AC POWER-DISTRIBUTION TERMINAL BLOCKS AS REQUIRED				DC POWER-DISTRIBUTION TERMINAL BLOCKS AS REQUIRED		SF-XXXX STARTER-CONTROL- WIRING TERMINAL BLOCKS
						191-200
						SPACE
						201-210
						SPARE

Figure 4-17F. Control-panel terminal-block layout for VAV HVAC system XX without return fan.



HVAC CONTROL PANEL

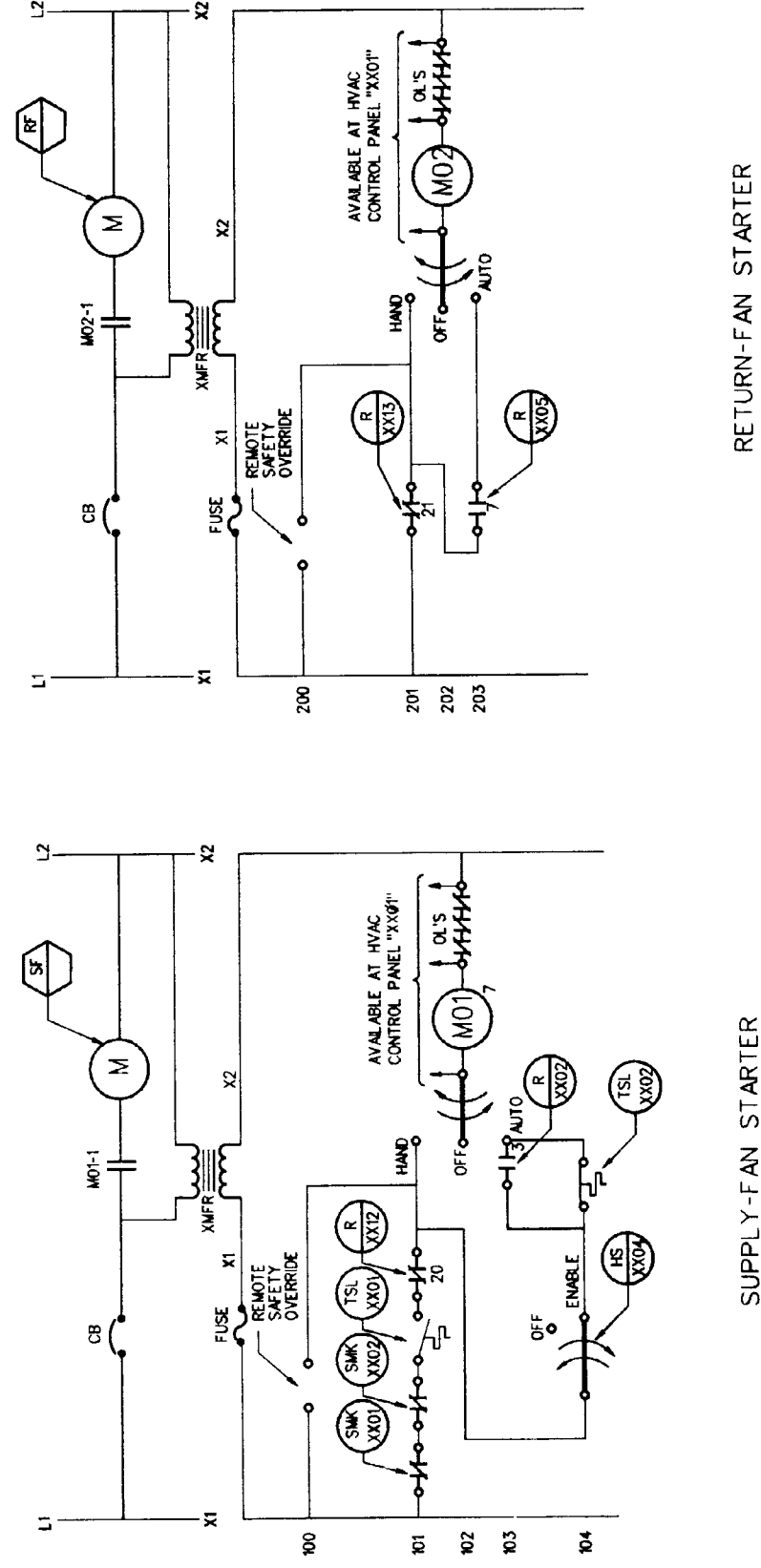
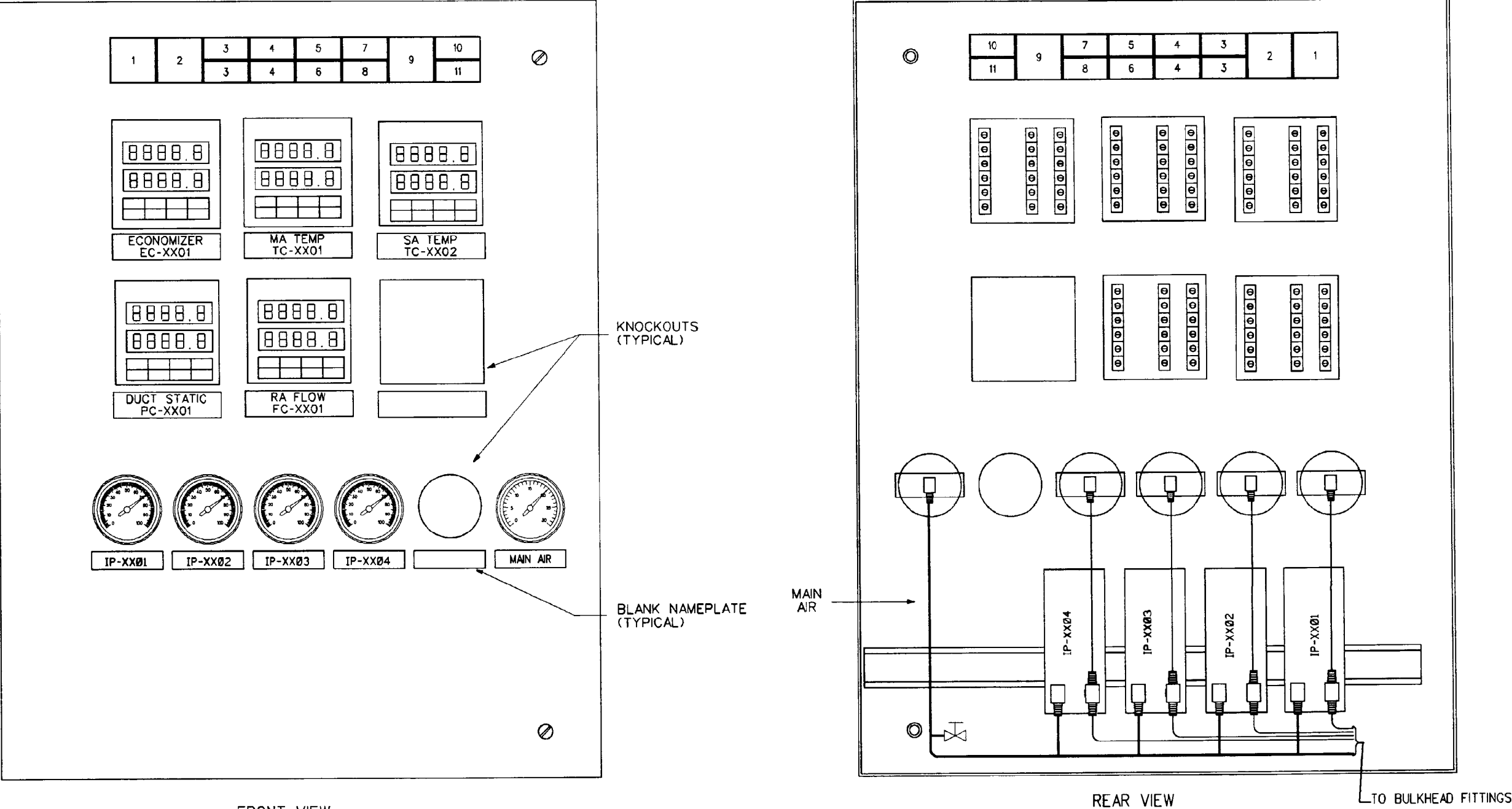


Figure 4-18B. Control-system ladder diagram for VAV HVAC system XX with return fan.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
MIXED-AIR TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	3-15 PSIG	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM AT MAXIMUM SUPPLY FAN TURN DOWN
	TC-XX01	MIXED-AIR TEMPERATURE CONTROLLER	55°F	40 TO 140°F	—
	TT-XX01	MIXED-AIR TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
	TT-XX02	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	TT-XX03	RETURN-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	EC-XX01	ECONOMIZER CONTROLLER	PV CONTACT CLOSE AT 73°F OPEN AT 71°F	-30 TO +130°F	DEV CONTACT CLOSE WHEN $\Delta T=8^\circ\text{F}$ OPEN WHEN $\Delta T=6^\circ\text{F}$
	TSL-XX01	LOW-TEMPERATURE PROTECTION THERMOSTAT	35°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
DISCHARGE-AIR TEMPERATURE	VLV-XX01	COOLING-COIL VALVE	—	3-15 PSIG	CV-20 CLOSE AGAINST 20 PSIG
	TC-XX02	FAN-DISCHARGE TEMPERATURE CONTROLLER	57°F	40 TO 140°F	—
	TT-XX04	FAN-DISCHARGE TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
SUPPLY-DUCT STATIC PRESSURE	DA-XX04	SUPPLY-FAN INLET-VANE ACTUATOR	—	3-15 PSIG	—
	PC-XX01	SUPPLY-DUCT STATIC-PRESSURE CONTROLLER	1.2 INCHES WATER	0.0-2.0 INCHES WATER	—
	OPT-XX01	SUPPLY-DUCT STATIC-PRESSURE TRANSMITTER	—	0.0-2.0 INCHES WATER	—
RETURN-FAN VOLUME	DA-XX05	RETURN-FAN INLET VANE ACTUATOR	—	3-15 PSIG	—
	FC-XX01	RETURN-FAN VOLUME CONTROLLER	SUPPLY FAN CFM MINUS 3000 CFM	0-20,000 CFM	—
	FT-XX01	SUPPLY-DUCT FLOW-RATE TRANSMITTER (FPM)	—	0-20,000 CFM	—
	FT-XX02	RETURN-DUCT FLOW TRANSMITTER (FPM)	—	0-20,000 CFM	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M,T,W,TH,F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M,T,W,TH,F	—
TERMINAL UNITS	VLV-XXXX	HEATING-COIL VALVE-SPACE XXXY	—	—	CV-0.7 CLOSE AGAINST 10PSIG
	•	•	•	•	•
	VLV-XXYY	HEATING-COIL VALVE-SPACE XXXY	—	—	CV-1.2 CLOSE AGAINST 10PSIG

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS, SIGNAL SELECTORS AND TERMINAL UNIT CONTROLLERS ARE NOT SHOWN

Figure 4-18C. Equipment for VAV HVAC system XX with return fan.



FRONT VIEW			REAR VIEW		
POSITION LEGEND	DEVICE TYPE	IDENTIFIER	POSITION LEGEND	DEVICE TYPE	IDENTIFIER
1 - RESET	NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH	HS-XX03	6 - SMOKE	PILOT LIGHT	PL-XX06
2 - STATIC RESET	NON-ILLUMINATED MOMENTARY PUSH BUTTON SWITCH	HS-XX02	7 - HIGH STATIC	PILOT LIGHT	PL-XX07
3 - AUTO/AUTO OVERRIDE	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX01	8 - FILTER	PILOT LIGHT	PL-XX04
4 - ENABLE/OFF	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX04	9 - OCC	PILOT LIGHT	PL-XX01
5 - LOW TEMP	PILOT LIGHT	PL-XX05	10 - VENT DELAY	PILOT LIGHT	PL-XX02
			11 - ECON	PILOT LIGHT	PL-XX03

Figure 4-18D. Control-panel interior-door layout for VAV HVAC system XX with return fan.

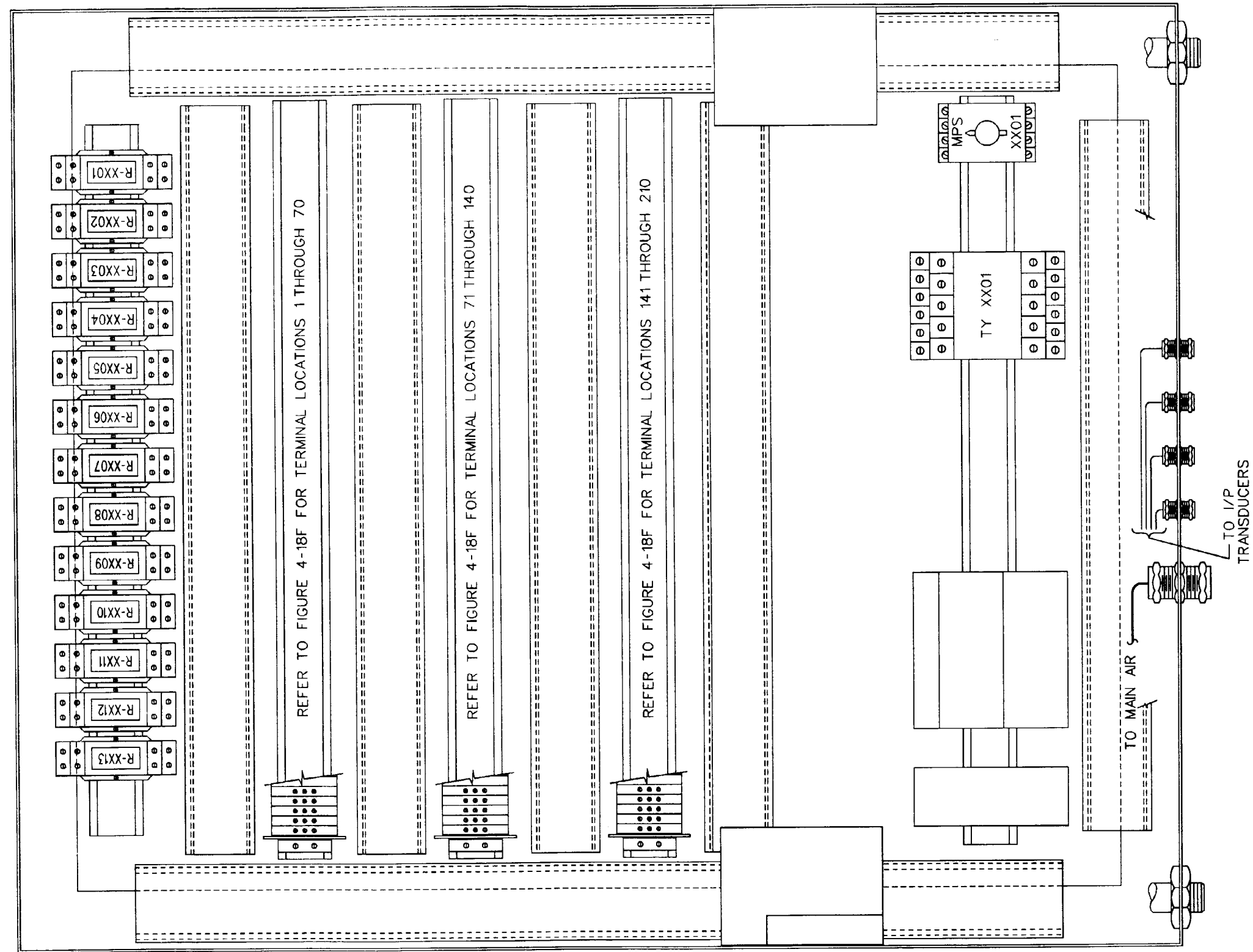


Figure 4-18E. Control-panel back-panel layout for VAV HVAC system XX with return fan.

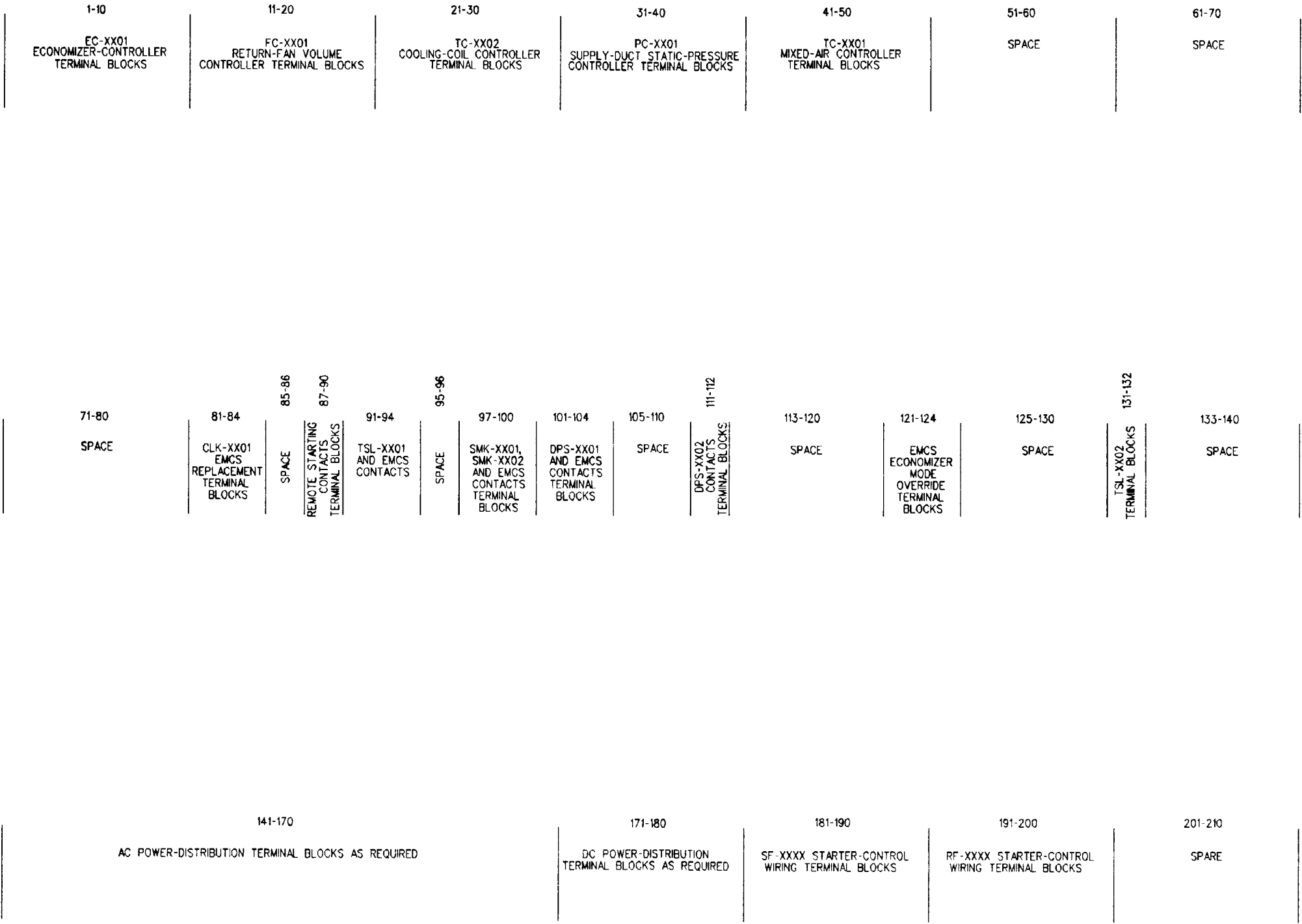


Figure 4-18F. Control-panel terminal-block layout for VAV HVAC system XX with return fan.

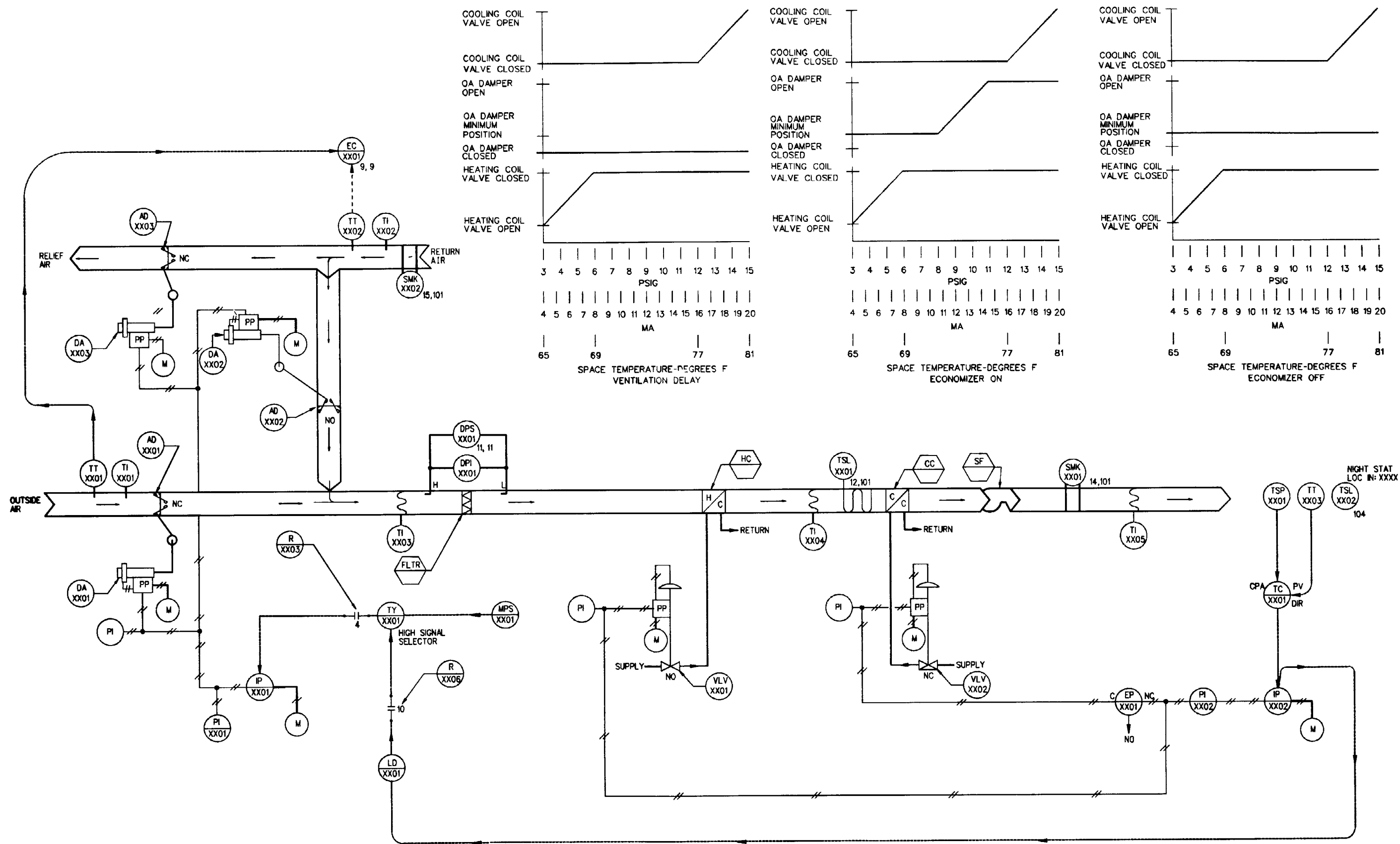
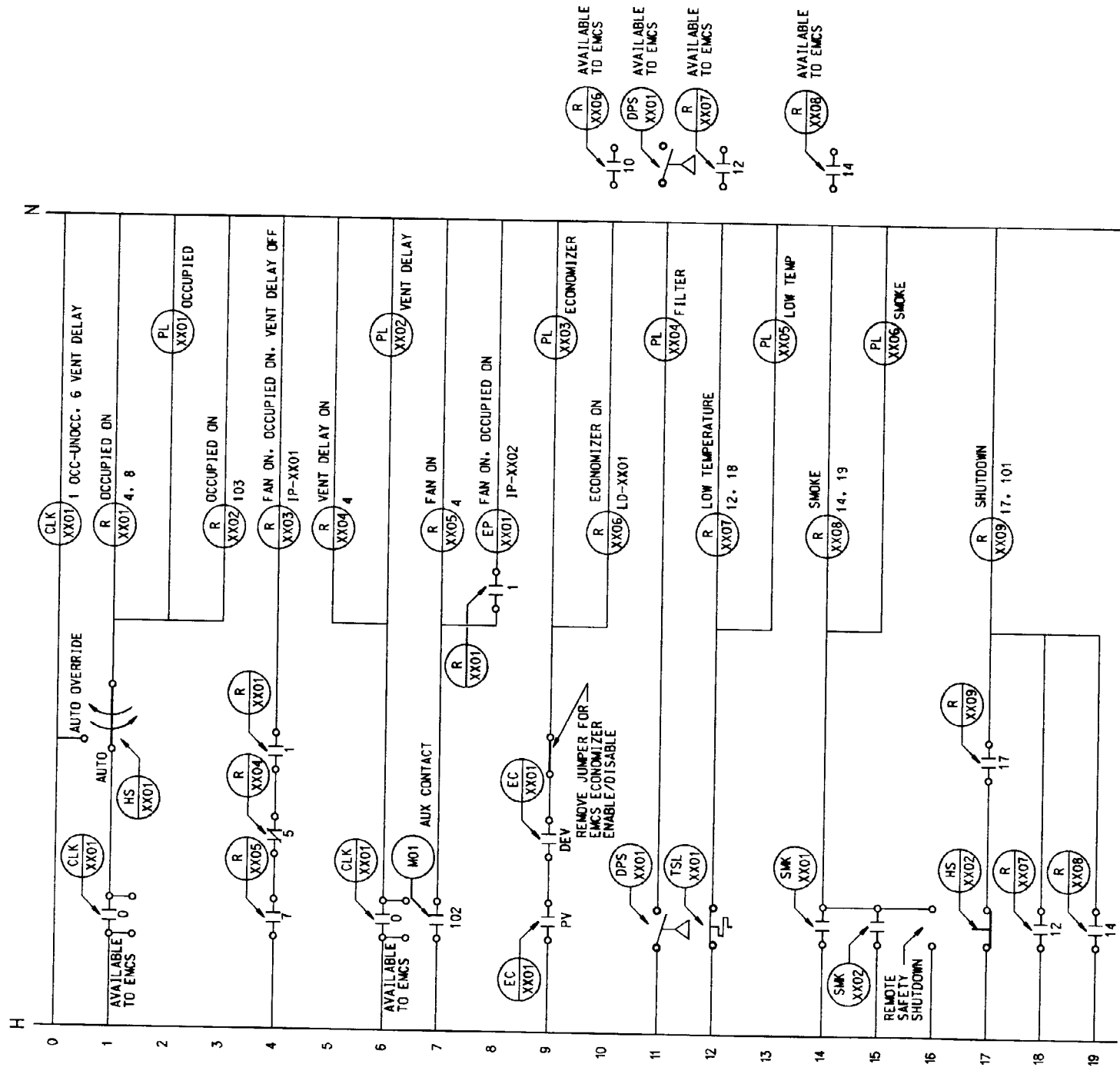


Figure 4-19A. Control-system schematic for single-zone HVAC control system XX.



HVAC CONTROL PANEL

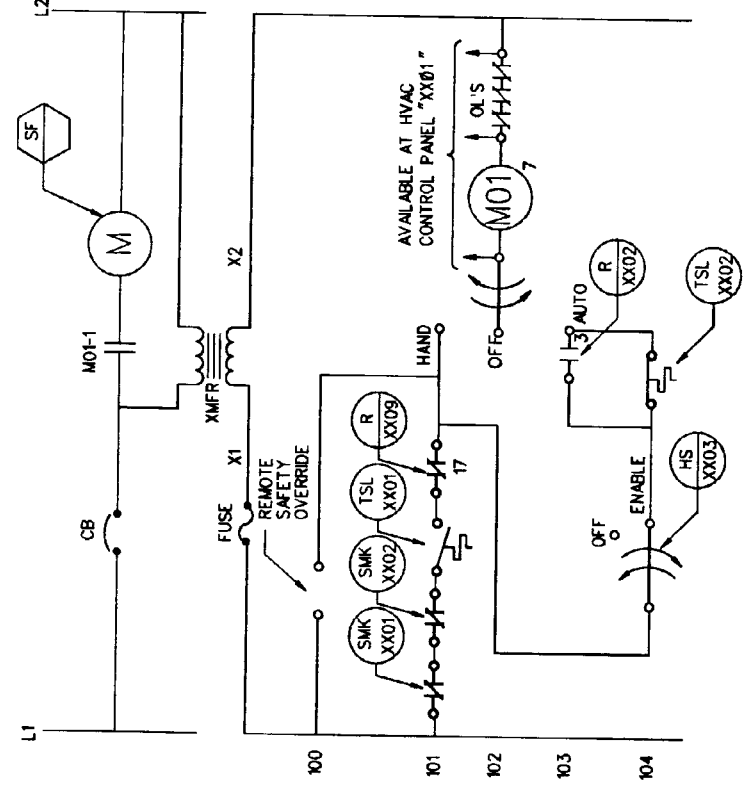
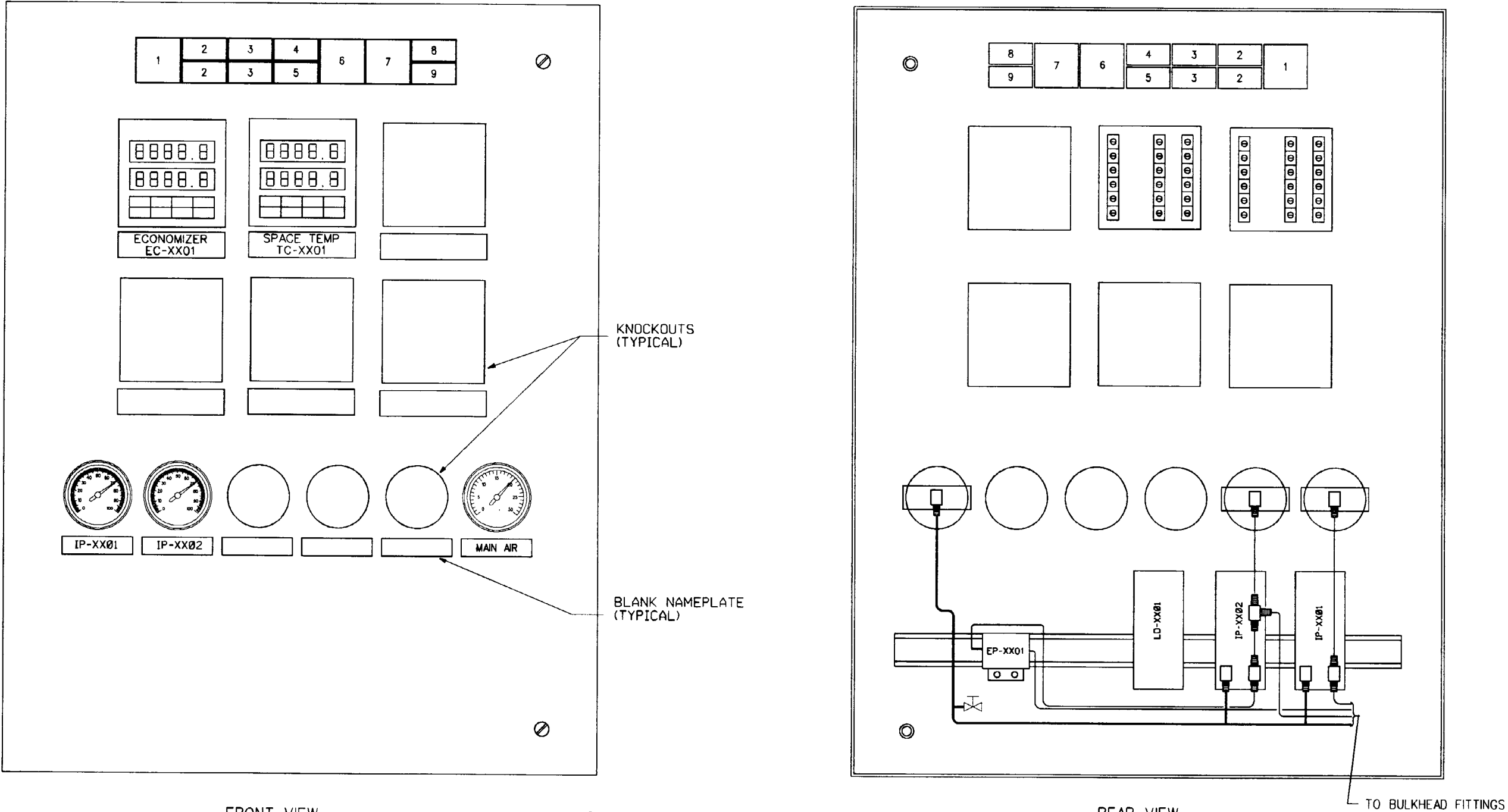


Figure 4-19B. Control-system ladder diagram for single-zone HVAC control system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
SPACE TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	7-11 PSIG	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	TT-XX02	RETURN-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	EC-XX01	ECONOMIZER CONTROLLER	PV CONTACT CLOSE AT 73°F OPEN AT 71°F	-30 TO +130°F	DEV CONTACT CLOSE WHEN $\Delta T=12^{\circ}\text{F}$ OPEN WHEN $\Delta T=10^{\circ}\text{F}$
	VLV-XX01	HEATING-COIL VALVE	—	3-6 PSIG	CV=12 CLOSE AGAINST 15 PSIG
	VLV-XX02	COOLING-COIL VALVE	—	12-15 PSIG	CV=20 CLOSE AGAINST 20 PSIG
	TC-XX01	SPACE-TEMPERATURE CONTROLLER	SET POINT =73°F PROP. BAND =45.7% MANUAL RESET =50%	50 TO 85°F	SET MAXIMUM LIMITS AVAILABLE TO OCCUPANT BY TSP-XX01 AT 66 TO 72°F
	TT-XX04	SPACE-TEMPERATURE TRANSMITTER	—	50 TO 85°F	—
	TSP-XX01	TEMPERATURE-SETPOINT DEVICE	4 MA = 50°F 20 MA = 85°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW LIMIT SPACE TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
MIXED-AIR TEMPERATURE	TSL-XX01	LOW-TEMPERATURE-PROTECTION THERMOSTAT	35°F	—	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M.T.W.TH.F	OPEN: SAT. SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M.T.W.TH.F	

NOTE:OTHER CONTROL DEVICES SUCH AS IPS, RELAYS AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 4-19C. Equipment for single-zone HVAC control system XX.



FRONT VIEW			SWITCH AND PILOT LIGHT LEGEND			REAR VIEW		
POSITION LEGEND	DEVICE TYPE	IDENTIFIER	POSITION LEGEND	DEVICE TYPE	IDENTIFIER			
1 - RESET	NON-ILLUMINATED MOMENTARY PUSH BUTTON SWITCH	HS-XX02	6 - FILTER	PILOT LIGHT	PL-XX04			
2 - AUTO/AUTO OVERRIDE	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX01	7 - OCC	PILOT LIGHT	PL-XX01			
3 - ENABLE/OFF	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX03	8 - VENT DELAY	PILOT LIGHT	PL-XX02			
4 - LOW TEMP	PILOT LIGHT	PL-XX05	9 - ECON	PILOT LIGHT	PL-XX03			
5 - SMOKE	PILOT LIGHT	PL-XX06						

Figure 4-19D. Control-panel interior-door layout for single-zone HVAC control system XX.

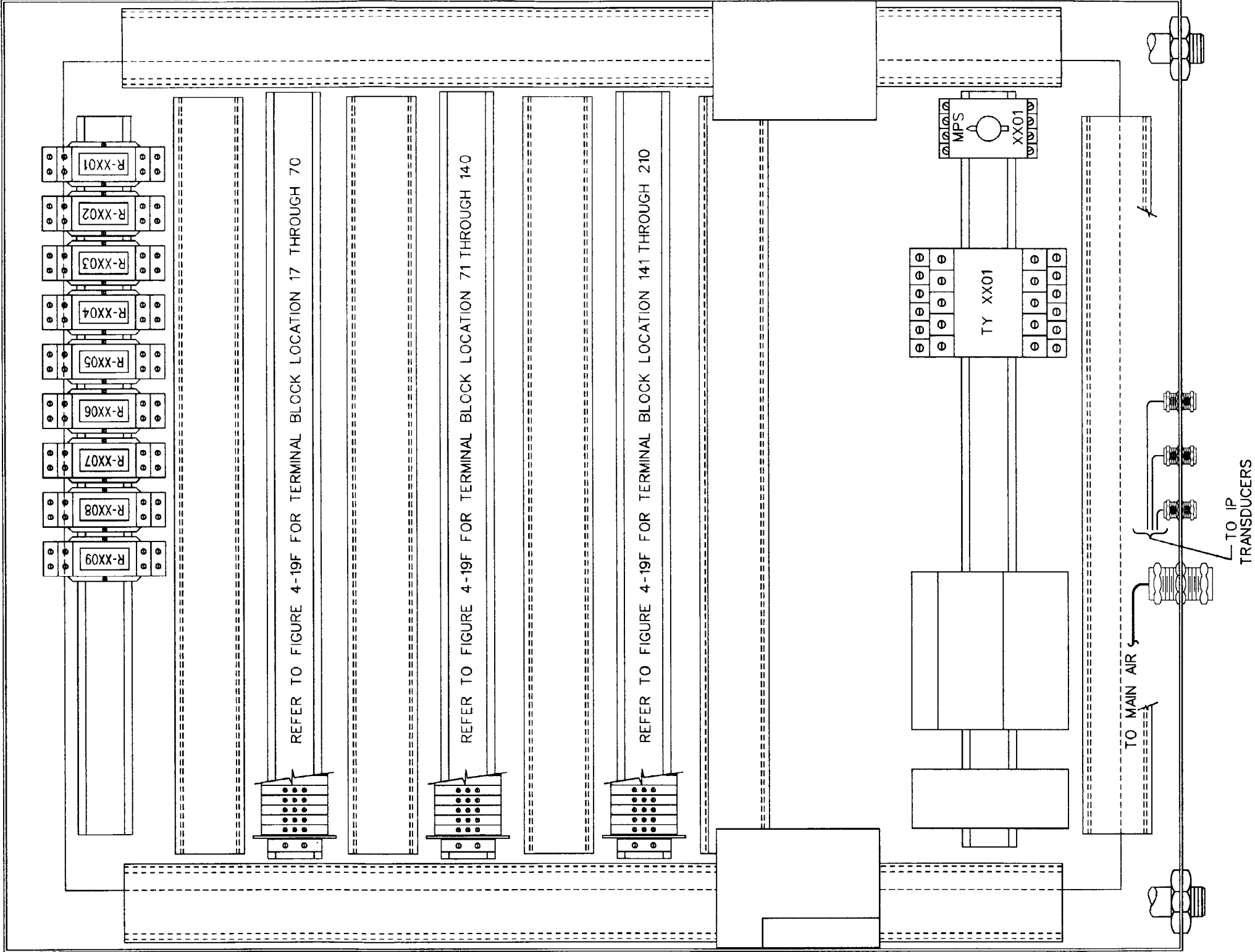


Figure 4-19E. Back-panel layout for single-zone HVAC control system XX control panel.

1-10	11-20	21-30	31-40	41-50	51-60	61-70
EC-XX01 ECONOMIZER-CONTROLLER TERMINAL BLOCKS	TC-XX01 SPACE-TEMPERATURE CONTROLLER TERMINAL BLOCKS	SPACE	SPACE	SPACE	SPACE	SPACE
71-80	81-84	85-86	87-90	91-94	95-96	97-100
SPACE	CLK-XX01 EMCS REPLACEMENT TERMINAL BLOCKS	SPACE	REMOTE STARTING CONTACTS TERMINAL BLOCKS	TSL-XX01 AND EMCS CONTACTS	SPACE	SMK-XX01, SMK-XX02 AND EMCS CONTACTS TERMINAL BLOCKS
						101-104
						DPS-XX01 AND EMCS CONTACTS TERMINAL BLOCKS
						105-110
						SPACE
						111-120
						SPACE
						121-124
						EMCS ECONOMIZER MODE OVERRIDE TERMINAL BLOCKS
						125-130
						SPACE
						131-132
						TSL-XX02 TERMINAL BLOCKS
						133-140
						SPACE
141-170			171-180		181-190	
AC POWER-DISTRIBUTION TERMINAL BLOCKS AS REQUIRED			DC POWER-DISTRIBUTION TERMINAL BLOCKS AS REQUIRED		SF-XXXX STARTER-CONTROL WIRING TERMINAL BLOCKS	
					191-200	
					SPARE	
					201-210	
					SPARE	

Figure 4-19F. Terminal-block layout for single-zone HVAC control system XX control panel.

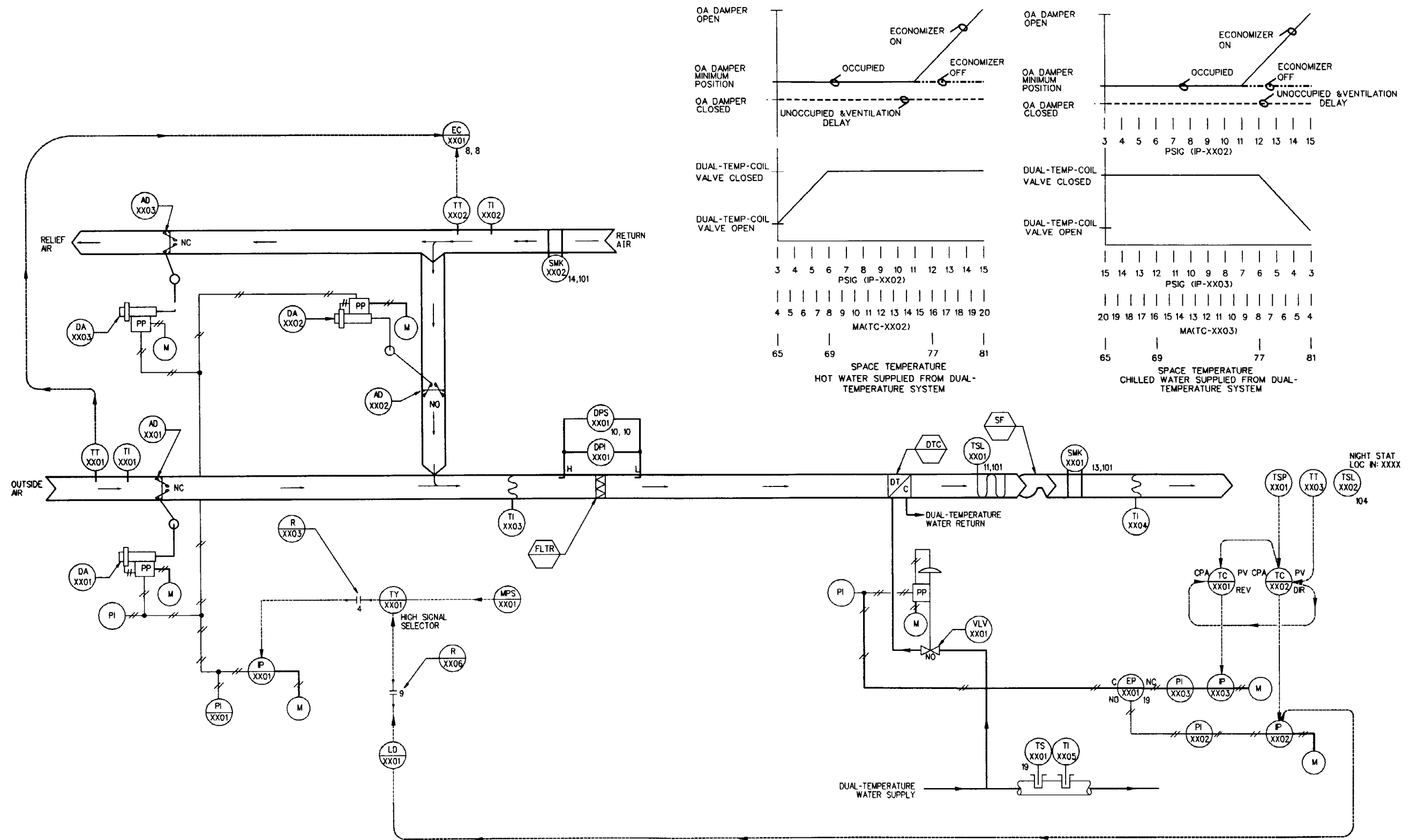


Figure 4-20A. Control-system schematic for dual-temperature-coil single-zone HVAC control system XX.

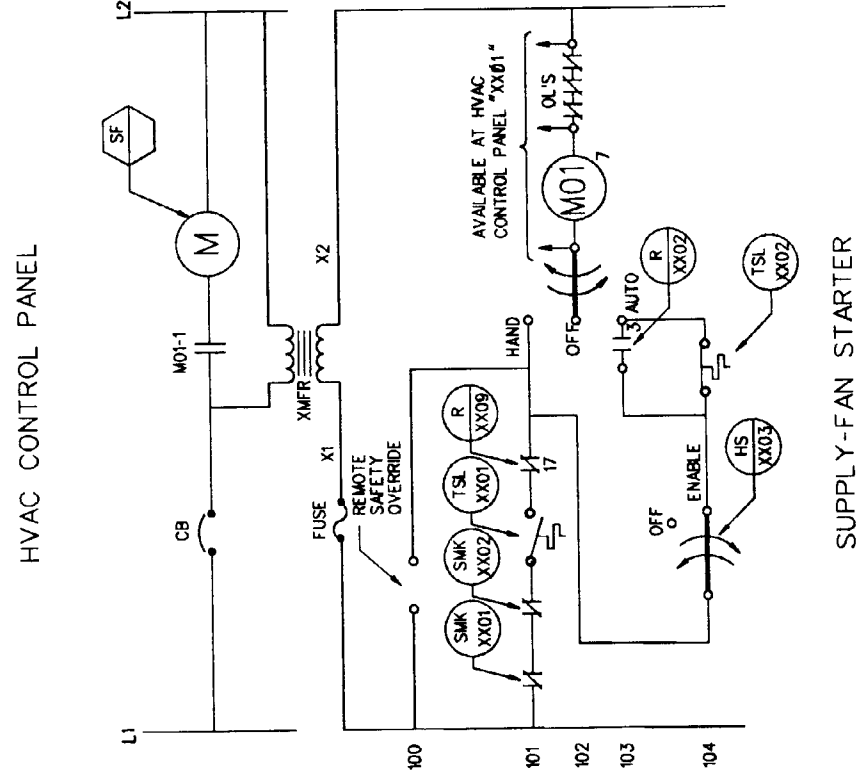
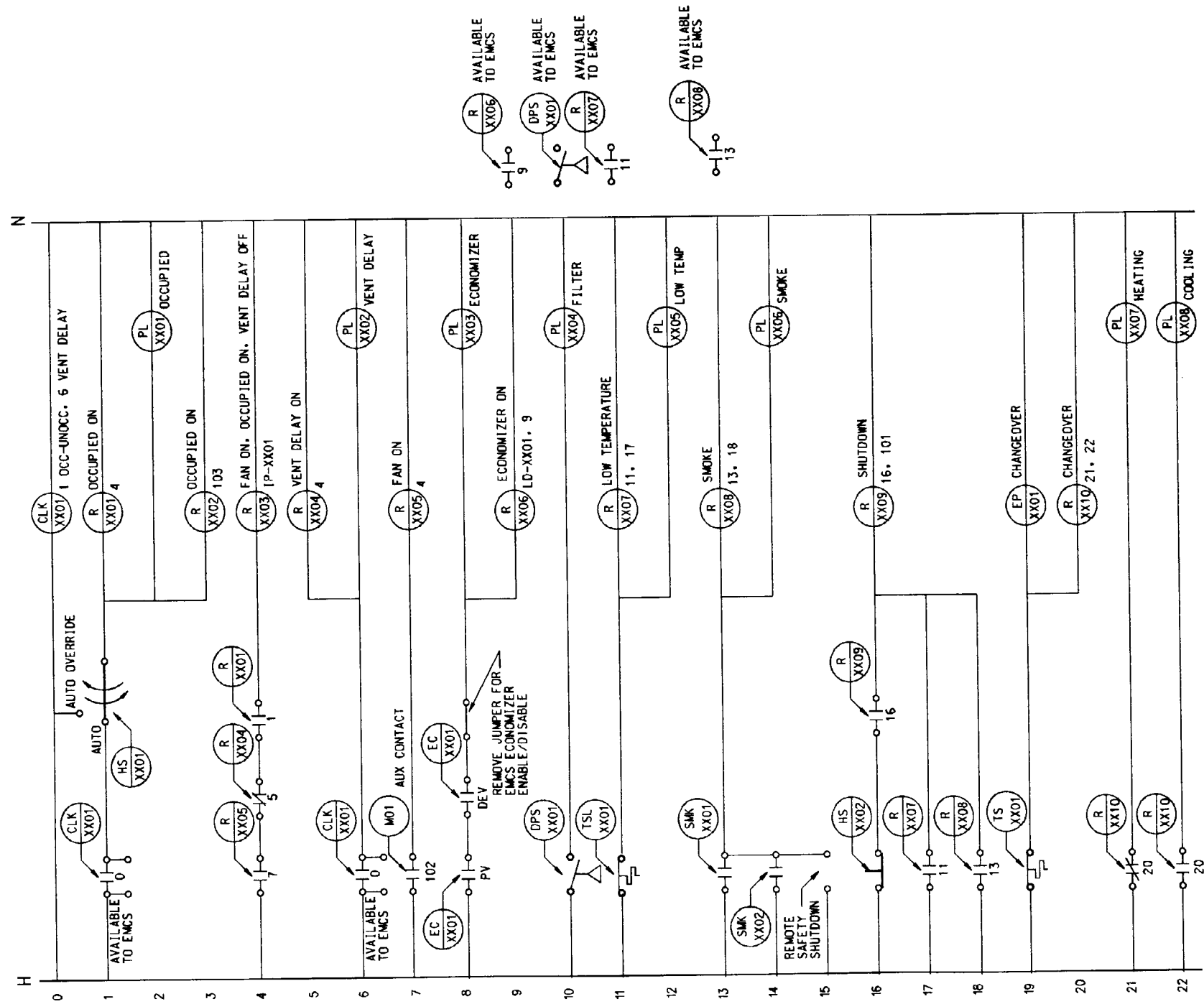


Figure 4-20B. Control-system ladder diagram for dual-temperature-coil single-zone HVAC control system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
SPACE TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	10-15 PSIG	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	TT-XX02	RETURN-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	EC-XX01	ECONOMIZER CONTROLLER	PV CONTACT CLOSE AT 73°F OPEN AT 71°F	-30 TO +130°F	DEV CONTACT CLOSE WHEN $\Delta T = 8^\circ\text{F}$ OPEN WHEN $\Delta T = 6^\circ\text{F}$
	VLV-XX01	DUAL-TEMPERATURE COIL VALVE	—	3-6 PSIG	CV = 20 CLOSE AGAINST 20 PSIG
	TC-XX01	SPACE-TEMPERATURE COOLING CONTROLLER	SET POINT = 73°F PROP BAND = 45.7% MANUAL RESET = 50%	50 TO 85°F	SET MAXIMUM LIMITS AVAILABLE TO OCCUPANT BY TSP-XX01 AT 76 TO 81°F
	TC-XX02	SPACE-TEMPERATURE HEATING CONTROLLER	SET POINT = 73°F PROP BAND = 45.7% MANUAL RESET = 50%	50 TO 85°F	SET MAXIMUM LIMITS AVAILABLE TO OCCUPANT BY TSP-XX01 AT 66 TO 71°F
	TT-XX04	SPACE-TEMPERATURE TRANSMITTER	—	50 TO 85°F	—
	TSP-XX01	TEMPERATURE-SETPOINT DEVICE	4 MA = 50°F 20 MA = 85°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
MIXED -AIR TEMPERATURE	TSL-XX01	LOW-TEMPERATURE-PROTECTION THERMOSTAT	35°F	—	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M.T.W.TH.F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M.T.W.TH.F	—
HEATING/COOLING CHANGE LEVEL	TS-XX01	AQUASTAT	OPEN AT 60°F CLOSE AT 50°F	10°F DIFFERENTIAL	—

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 4-20C. Equipment for dual-temperature-coil single-zone HVAC control system XX.

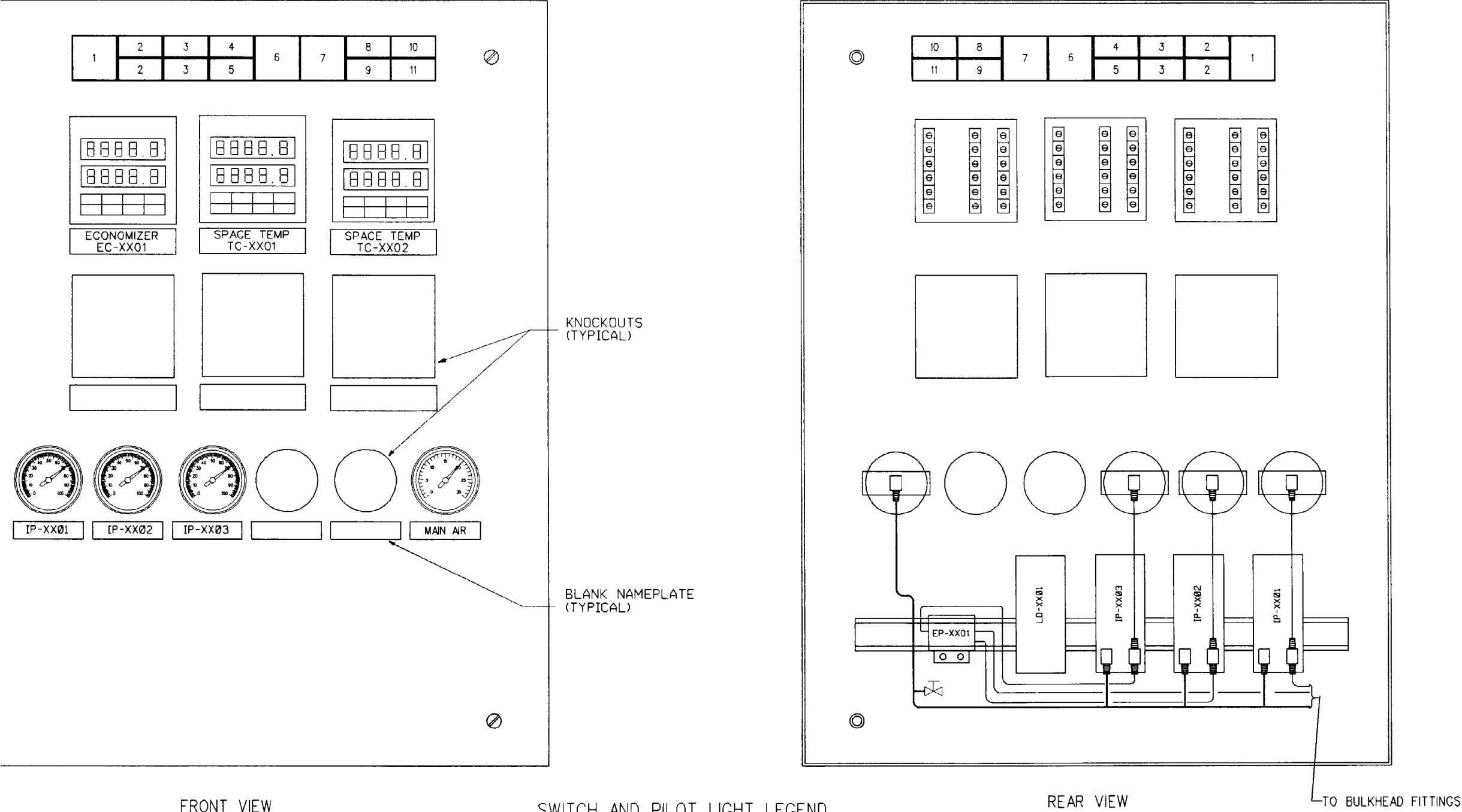


Figure 4-20D. Control-panel interior-door layout for dual-temperature-coil single-zone HVAC control system XX.

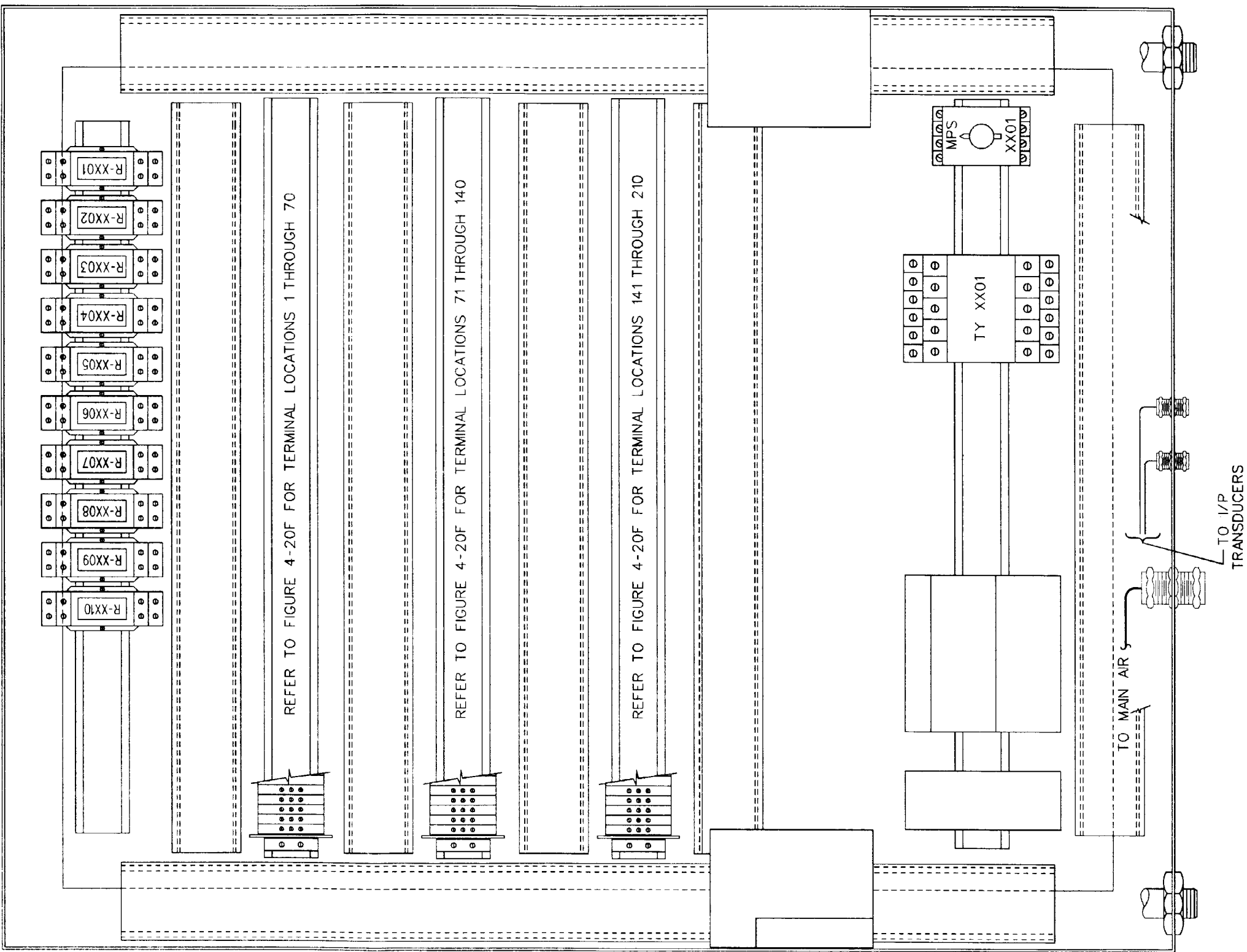


Figure 4-20E. Back-panel layout for dual-temperature-coil single zone HVAC control system XX control panel.

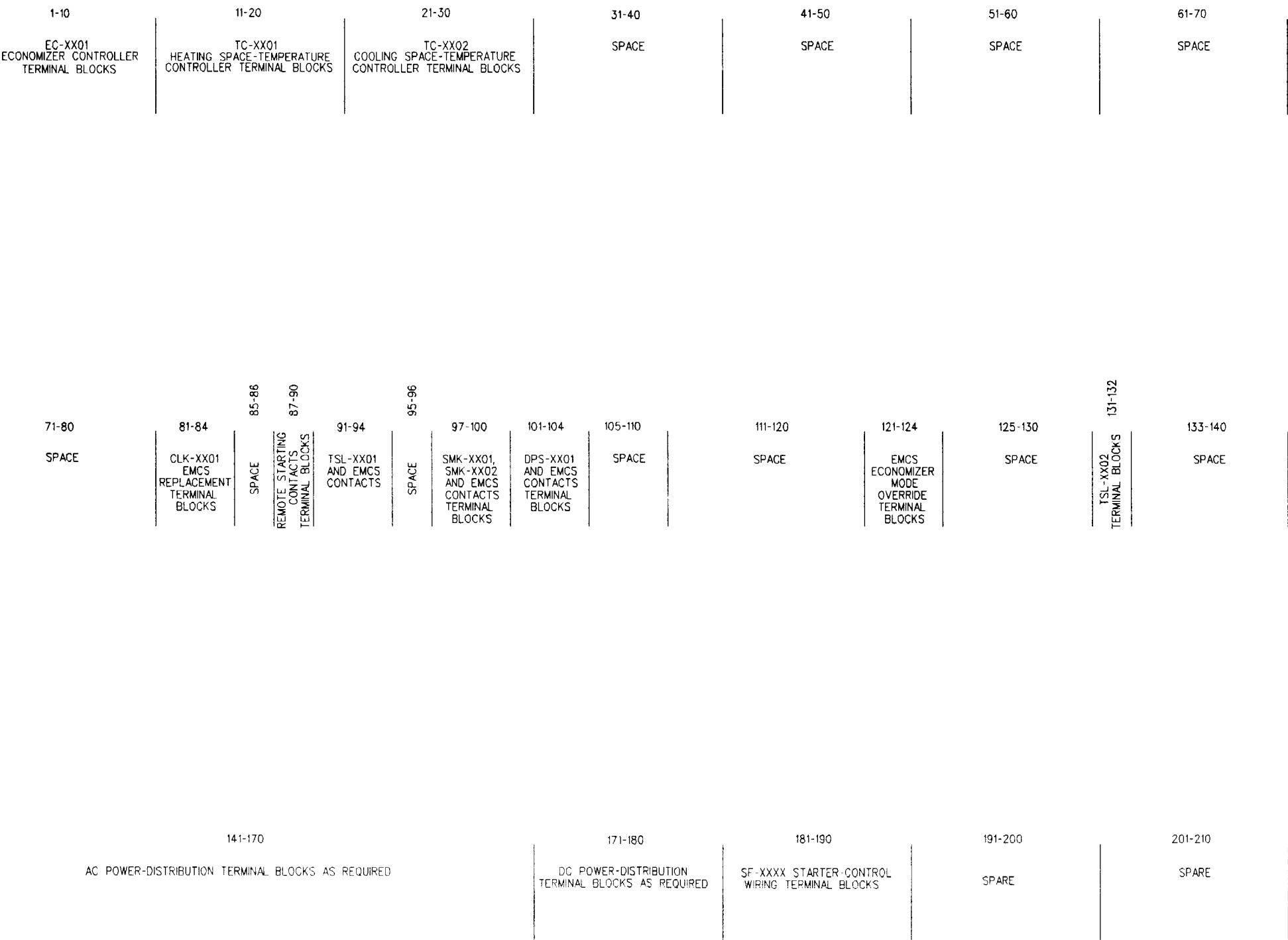


Figure 4-20F. Terminal-block layout for dual-temperature-coil single-zone HVAC control system XX control panel.

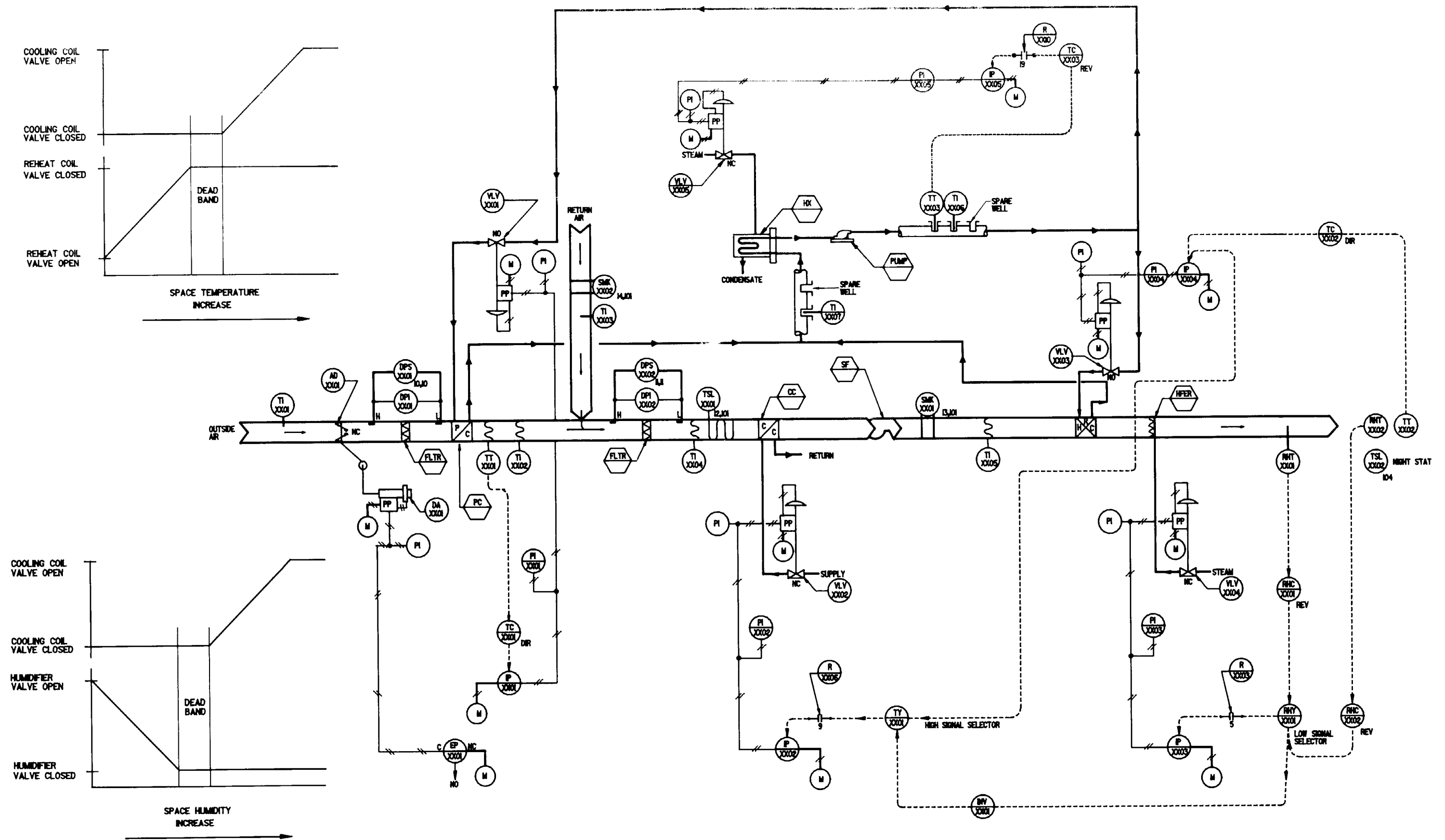
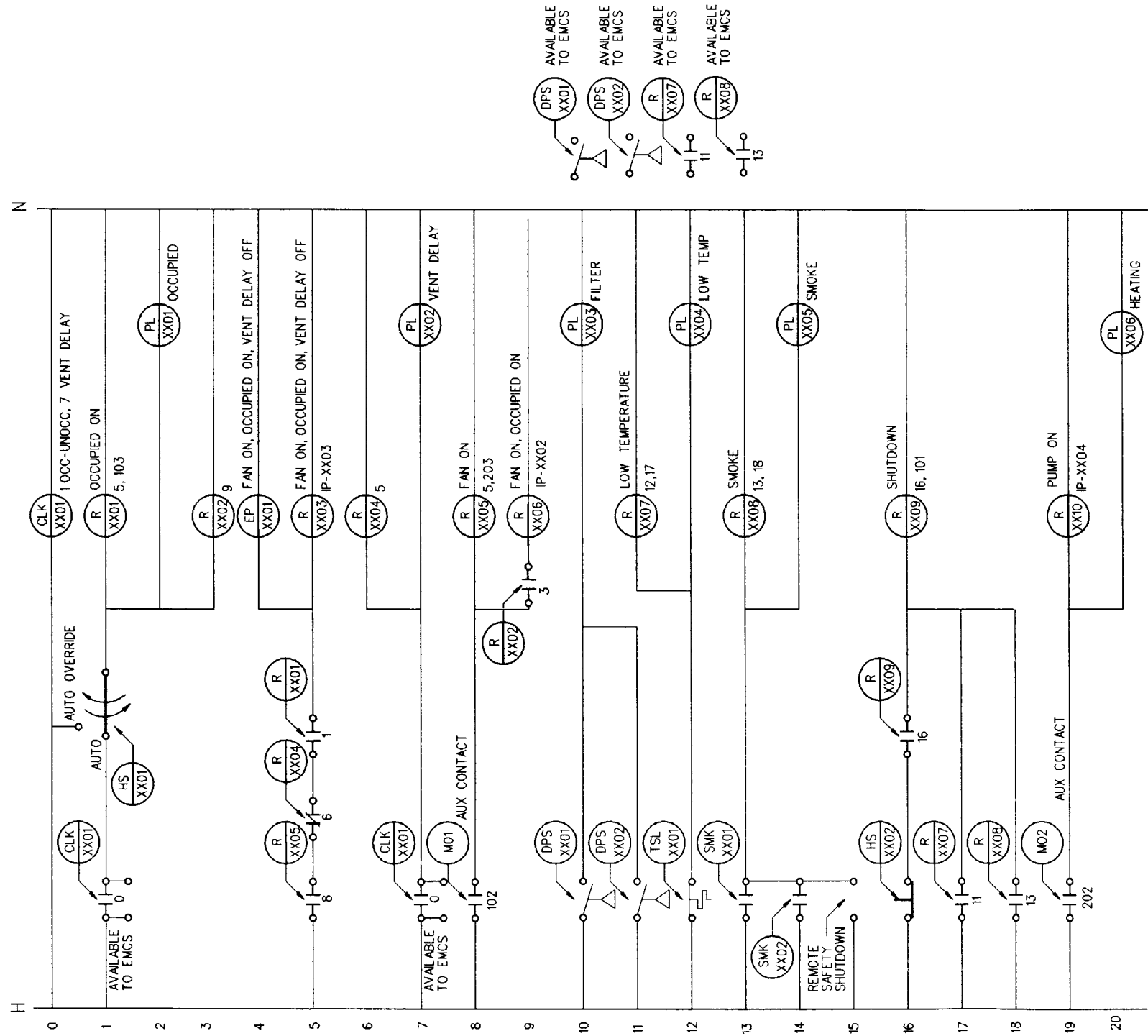


Figure 4-21A. Control-system schematic for single-zone HVAC system XX with humidity control.



HVAC CONTROL PANEL

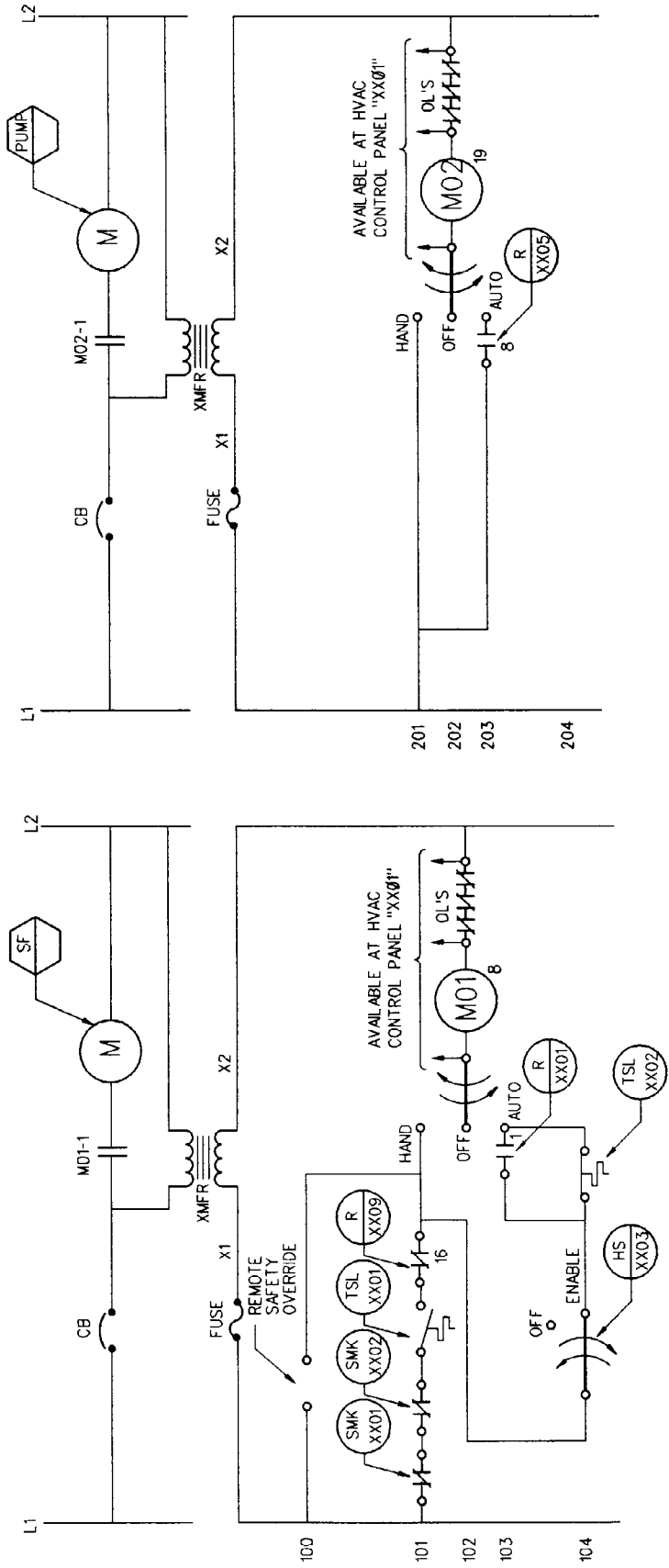
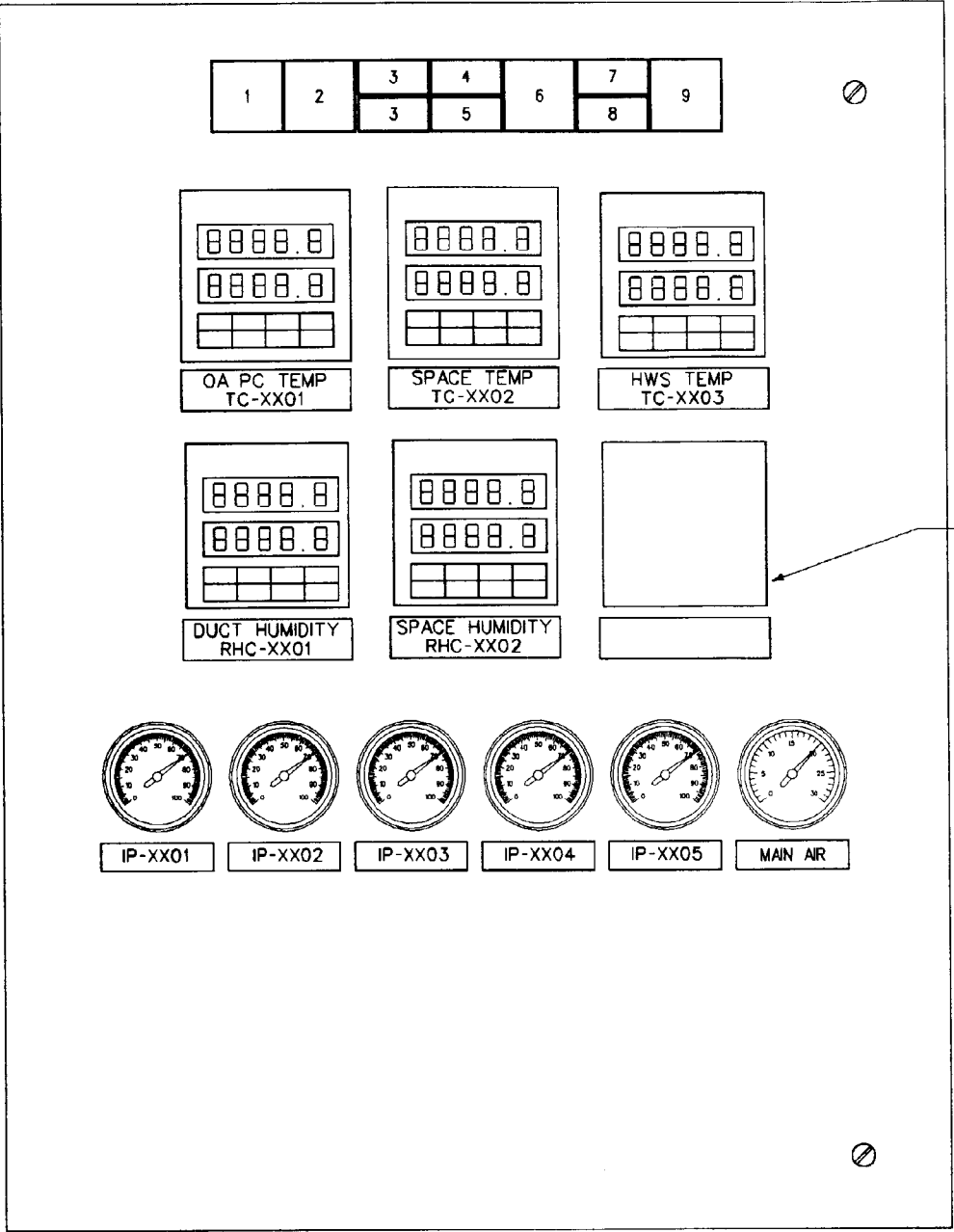


Figure 4-21B. Control-system ladder diagram for single-zone HVAC system XX with humidity control.

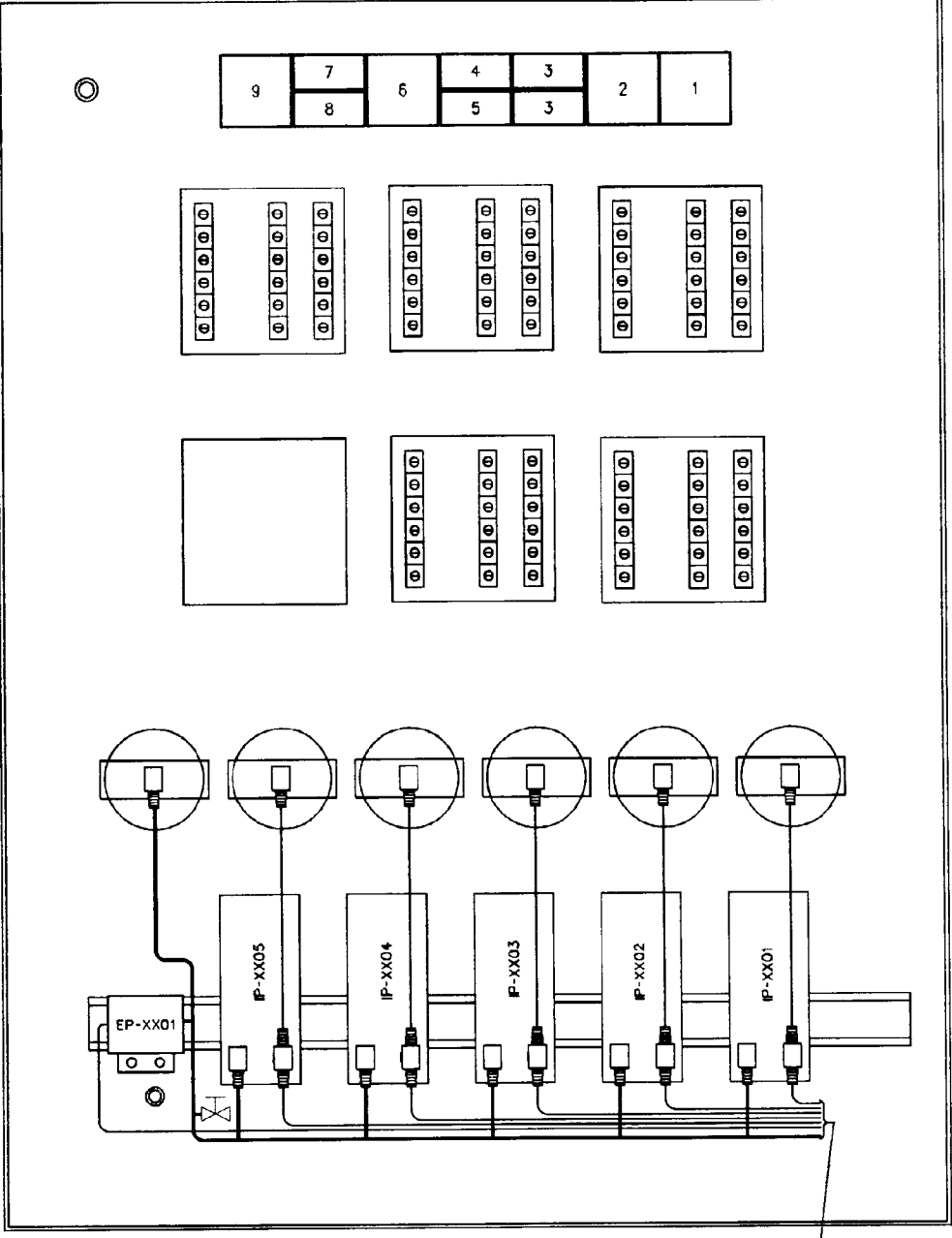
LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
OUTSIDE AIR	DA-XX01	DAMPER ACTUATOR	—	SPRING RANGE	—
PREHEAT-COIL TEMPERATURE	VLV-XX01	PREHEAT-COIL VALVE	—	3-15 PSIG	CV=12 CLOSE AGAINST 15 PSIG
	TC-XX01	PREHEAT-COIL TEMPERATURE CONTROLLER	45°F	40 TO 140°F	—
	TT-XX01	PREHEAT-TEMPERATURE TRANSMITTER	—	40 TO 140°F	—
MIXED-AIR TEMPERATURE	TSL-XX01	LOW-TEMPERATURE-PROTECTION THERMOSTAT	35°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
SPACE TEMPERATURE	VLV-XX03	REHEAT-COIL VALVE	—	3-8 PSIG	CV=2.5 CLOSE AGAINST 15 PSIG
	TC-XX02	SPACE-TEMPERATURE CONTROLLER	73°F	50 TO 85°F	—
	TT-XX02	SPACE-TEMPERATURE TRANSMITTER	—	50 TO 85°F	—
	VLV-XX02	COOLING-COIL VALVE	—	10-15 PSIG	CV=20 CLOSE AGAINST 20 PSIG
RELATIVE HUMIDITY	VLV-XX04	HUMIDIFIER VALVE	—	10-15 PSIG	CV=7 CLOSE AGAINST 10 PSIG
	RHC-XX01 PROP. ONLY	SUPPLY-DUCT RELATIVE HUMIDITY HIGH LIMIT	90% RH P.B.=10%	0 TO 100% RH	—
	RHT-XX01, 02	RELATIVE HUMIDITY TRANSMITTER	—	0 TO 100% RH	—
	RHC-XX02	SPACE RELATIVE HUMIDITY CONTROLLER	50% RH	0 TO 100% RH	—
HYDRONIC HEATING	RD-4-21D	CONVERTOR VALVE	—	3-15 PSIG	CV=7 CLOSE AGAINST 10 PSIG
	TC-XX03	HYDRONIC-HEATING TEMPERATURE CONTROLLER	200°F	100 TO 250°F	—
	TT-XX03	HYDRONIC-HEATING TEMPERATURE TRANSMITTER	—	100 TO 250°F	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M,T,W,Th,F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M,T,W,Th,F	

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS, AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 4-21C. Equipment for single-zone HVAC system XX with humidity control.



FRONT VIEW



REAR VIEW

POSITION LEGEND	DEVICE TYPE	IDENTIFIER
1 - RESET	NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH	HS-XX02
2 - AUTO/AUTO OVERRIDE	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX01
3 - ENABLE/OFF	ILLUMINATED MAINTAINED-CONTACT INTERLOCKED SWITCHES	HS-XX03
4 - LOW TEMP	PILOT LIGHT	PL-XX04
5 - SMOKE	PILOT LIGHT	PL-XX05
6 - FILTER	PILOT LIGHT	PL-XX03

SWITCH AND PILOT LIGHT LEGEND

POSITION LEGEND	DEVICE TYPE	IDENTIFIER
7 - OCC	PILOT LIGHT	PL-XX01
8 - VENT DELAY	PILOT LIGHT	PL-XX02
9 - HEATING	PILOT LIGHT	PL-XX06

Figure 4-21D. Control-panel interior-door layout for single-zone HVAC system XX with humidity control.

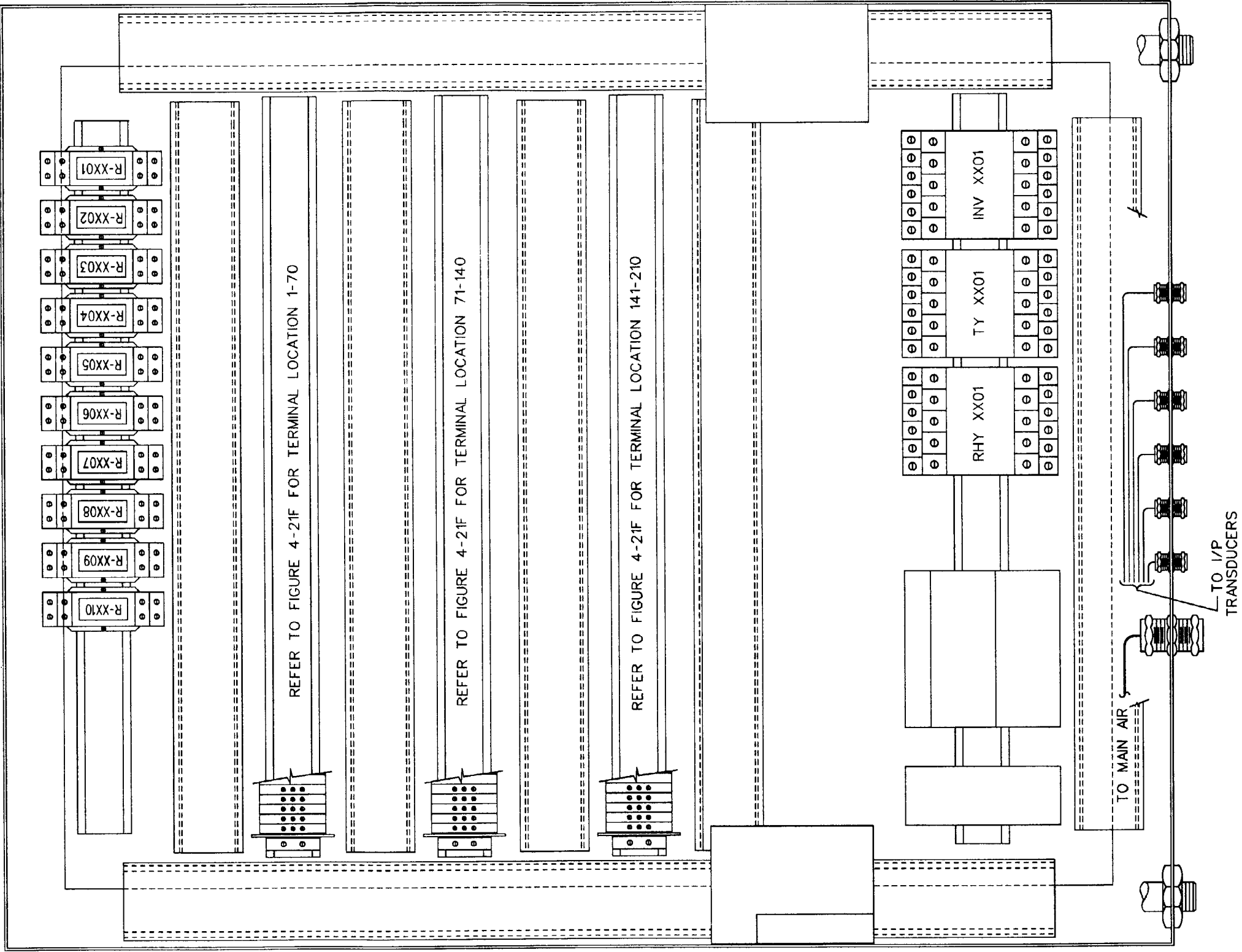
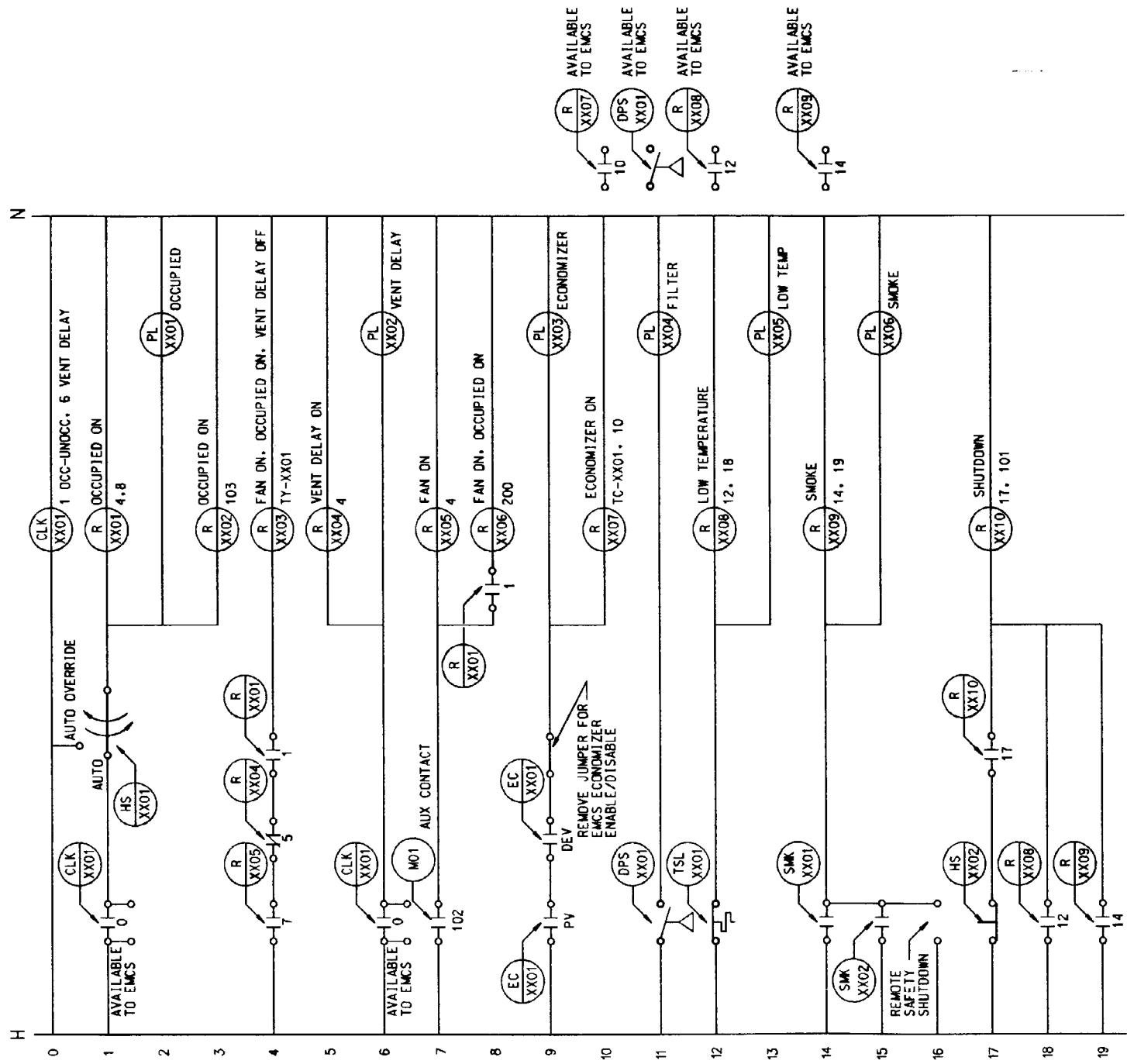


Figure 4-21E. Control-panel back-panel layout for single-zone HVAC system XX with humidity control.

1-10	11-20	21-30	31-40	41-50	51-60	61-70
TC-XX01 OUTSIDE-AIR PREHEATER TEMPERATURE CONTROLLER TERMINAL BLOCKS	TC-XX02 SPACE-TEMPERATURE CONTROLLER TERMINAL BLOCKS	TC-XX03 HEATING-SUPPLY-TEMPERATURE CONTROLLER TERMINAL BLOCKS	RHC-XX01 DUCT RELATIVE-HUMIDITY CONTROLLER TERMINAL BLOCKS	RHC-XX02 SPACE RELATIVE-HUMIDITY CONTROLLER TERMINAL BLOCKS	SPACE	SPACE
71-80	81-84	85-86	87-90	91-94	95-96	97-100
SPACE	CLK-XX01 EMCS REPLACEMENT TERMINAL BLOCKS	SPACE	REMOTE STARTING CONTACTS TERMINAL BLOCKS	TSL-XX01 AND EMCS CONTACTS	SPACE	SMK-XX01, SMK-XX02 AND EMCS CONTACTS TERMINAL BLOCKS
						101-104
						DPS-XX01 AND EMCS CONTACTS TERMINAL BLOCKS
						105-110
						DPS-XX02 AND EMCS CONTACTS TERMINAL BLOCKS
						111-120
						SPACE
						121-130
						SPACE
						131-132
						TSL-XX02 TERMINAL BLOCKS
						133-140
						SPACE
141-170				171-180		181-190
AC POWER-DISTRIBUTION TERMINAL BLOCKS AS REQUIRED				DC POWER-DISTRIBUTION TERMINAL BLOCKS AS REQUIRED		SF-XXXX STARTER-CONTROL WIRING TERMINAL BLOCKS
						191-200
						PUMP-XXXX STARTER-CONTROL WIRING TERMINAL BLOCKS
						201-210
						SPARE

Figure 4-21F. Control-panel terminal-block layout for single-zone HVAC system XX with humidity control.



HVAC CONTROL PANEL

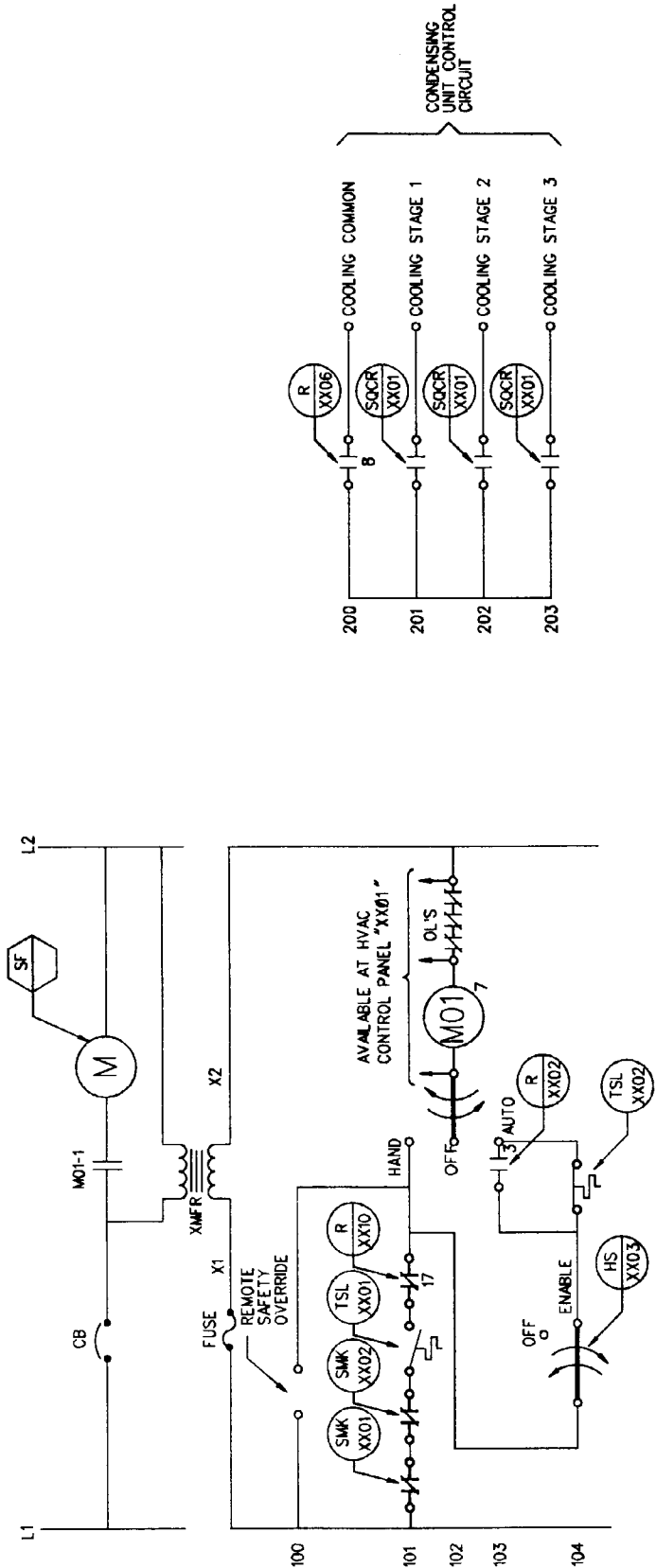
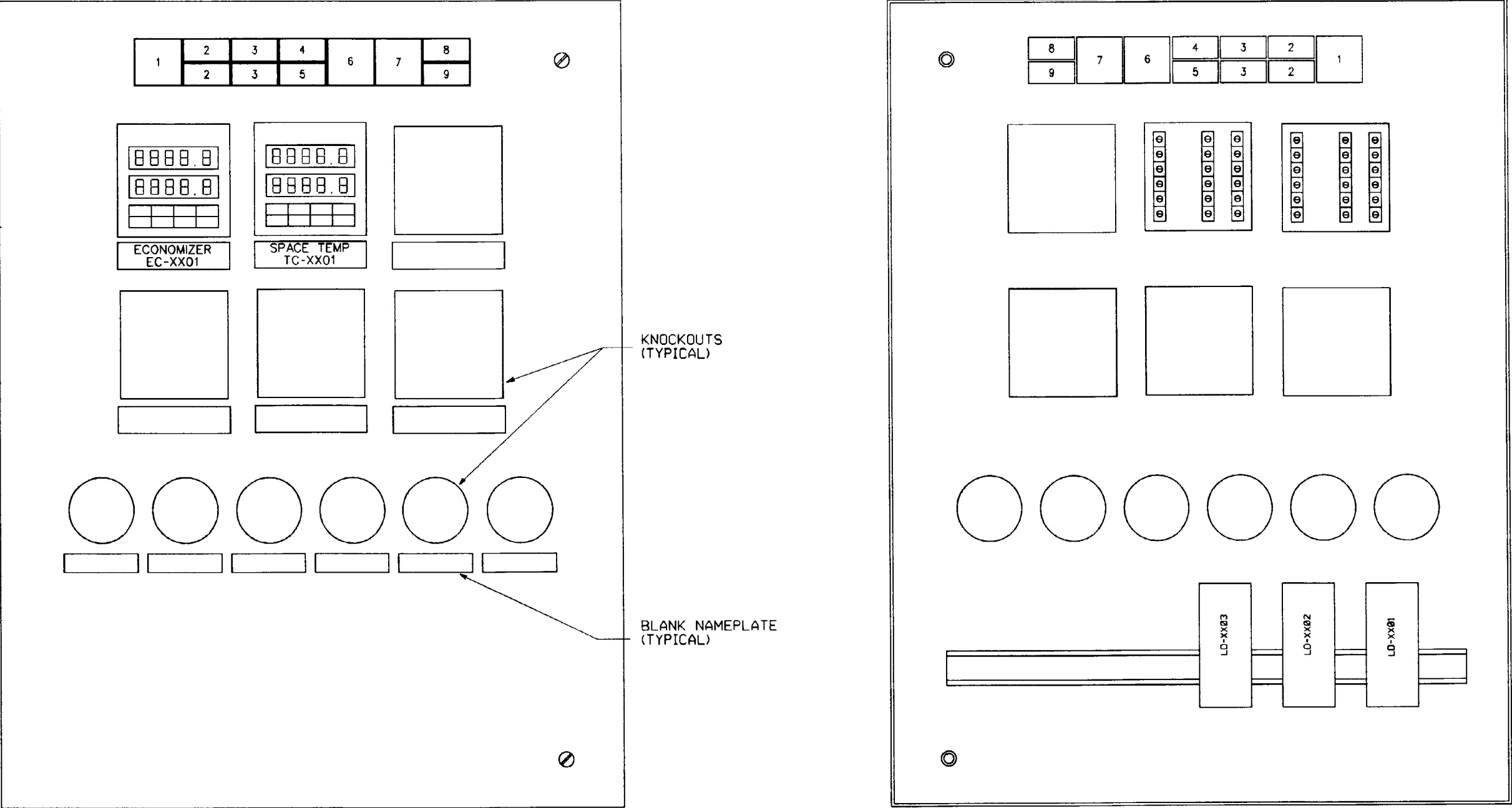


Figure 4-22B. Control-system ladder diagram for DX-coil single-zone HVAC system XX.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
SPACE TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	10 TO 15 MA	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	TT-XX02	RETURN-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130°F	—
	EC-XX01	ECONOMIZER CONTROLLER	PV CONTACT CLOSE AT 73°F OPEN AT 71°F	-30 TO +130°F	DEV CONTACT CLOSE WHEN $\Delta T = 8^\circ\text{F}$ OPEN WHEN $\Delta T = 6^\circ\text{F}$
	VLV-XX01	HEATING-COIL VALVE	—	4 TO 8 MA	CV=12 CLOSE AGAINST 15 PSIG
	SOCR-XX01	COOLING-COIL SEQUENCER	—	STAGE 1 ON = 18mA STAGE 2 ON = 19mA STAGE 3 ON = 20mA	OFF = ON - 2MA
	TC-XX01	SPACE-TEMPERATURE CONTROLLER	SET POINT=73°F PROP BAND = 45.7% MANUAL RESET = 50%	—	SET MAXIMUM LIMITS AVAILABLE TO OCCUPANT BY TSP-XX01 AT 66 TO 72°F
	TT-XX03	SPACE-TEMPERATURE TRANSMITTER	4 MA = 50°F 20 MA = 85°F	50 TO 85°F	—
	TSP-XX01	TEMPERATURE-SETPOINT DEVICE	4 MA = 50°F 20 MA = 85°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
MIXED-AIR TEMPERATURE	TSL-XX01	LOW-TEMPERATURE-PROTECTION THERMOSTAT	35°F	—	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M.T.W.TH.F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M.T.W.TH.F	

NOTE: OTHER CONTROL DEVICES SUCH AS RELAYS AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 4-22C. Equipment for DX-coil single-zone HVAC system XX.



FRONT VIEW			SWITCH AND PILOT LIGHT LEGEND			REAR VIEW		
POSITION LEGEND	DEVICE TYPE	IDENTIFIER	POSITION LEGEND	DEVICE TYPE	IDENTIFIER	POSITION LEGEND	DEVICE TYPE	IDENTIFIER
1 - RESET	NON-ILLUMINATED MOMENTARY PUSH BUTTON SWITCH	HS-XX02	6 - FILTER	PILOT LIGHT	PL-XX04			
2 - AUTO/AUTO OVERRIDE	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX01	7 - OCC	PILOT LIGHT	PL-XX01			
3 - ENABLE/OFF	ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES	HS-XX03	8 - VENT DELAY	PILOT LIGHT	PL-XX02			
4 - LOW TEMP	PILOT LIGHT	PL-XX05	9 - ECON	PILOT LIGHT	PL-XX03			
5 - SMOKE	PILOT LIGHT	PL-XX06						

Figure 4-22D. Control-panel interior-door layout for DX-coil single-zone HVAC system XX.

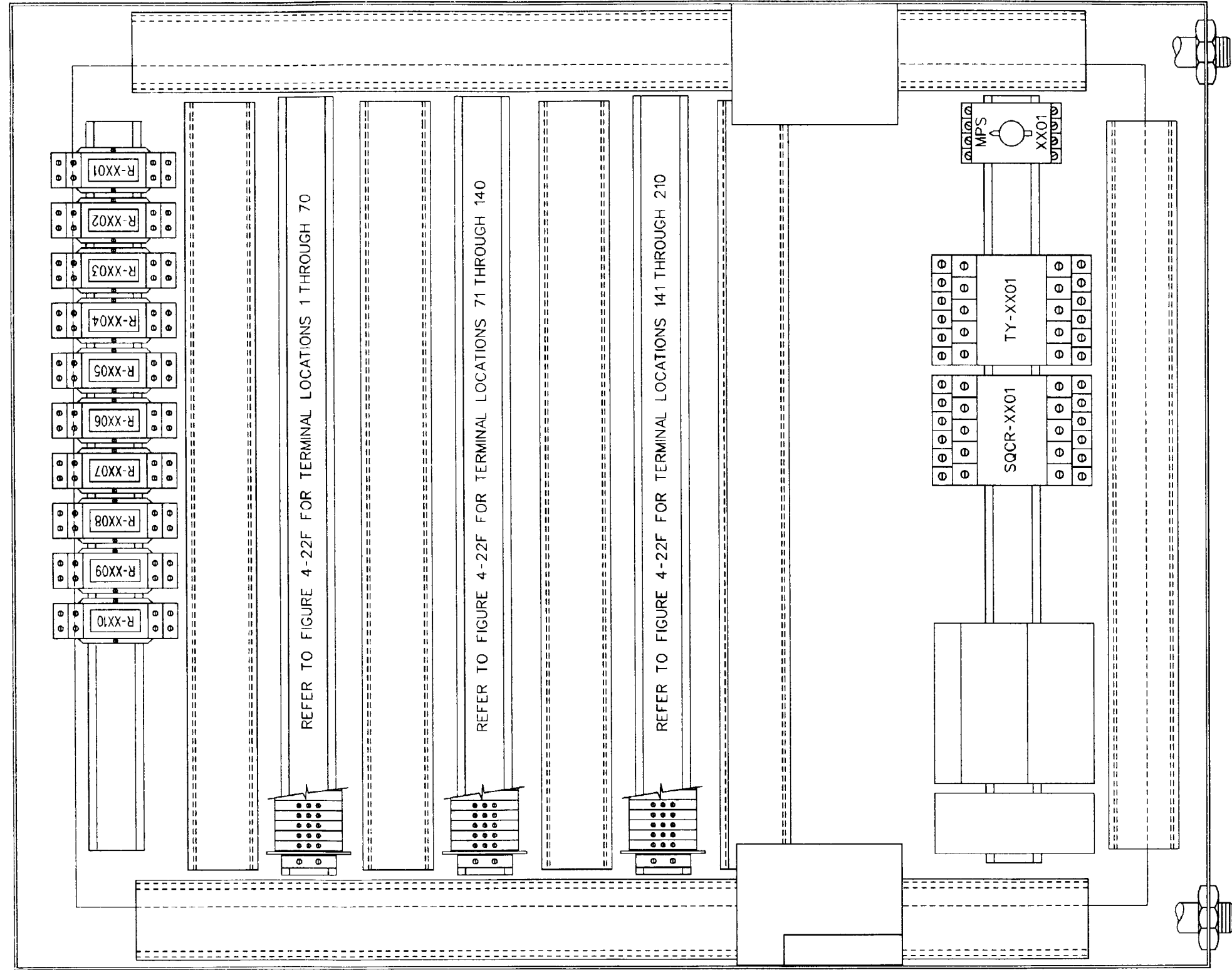


Figure 4-22E. Back-panel layout for DX-coil single-zone HVAC system XX control panel.

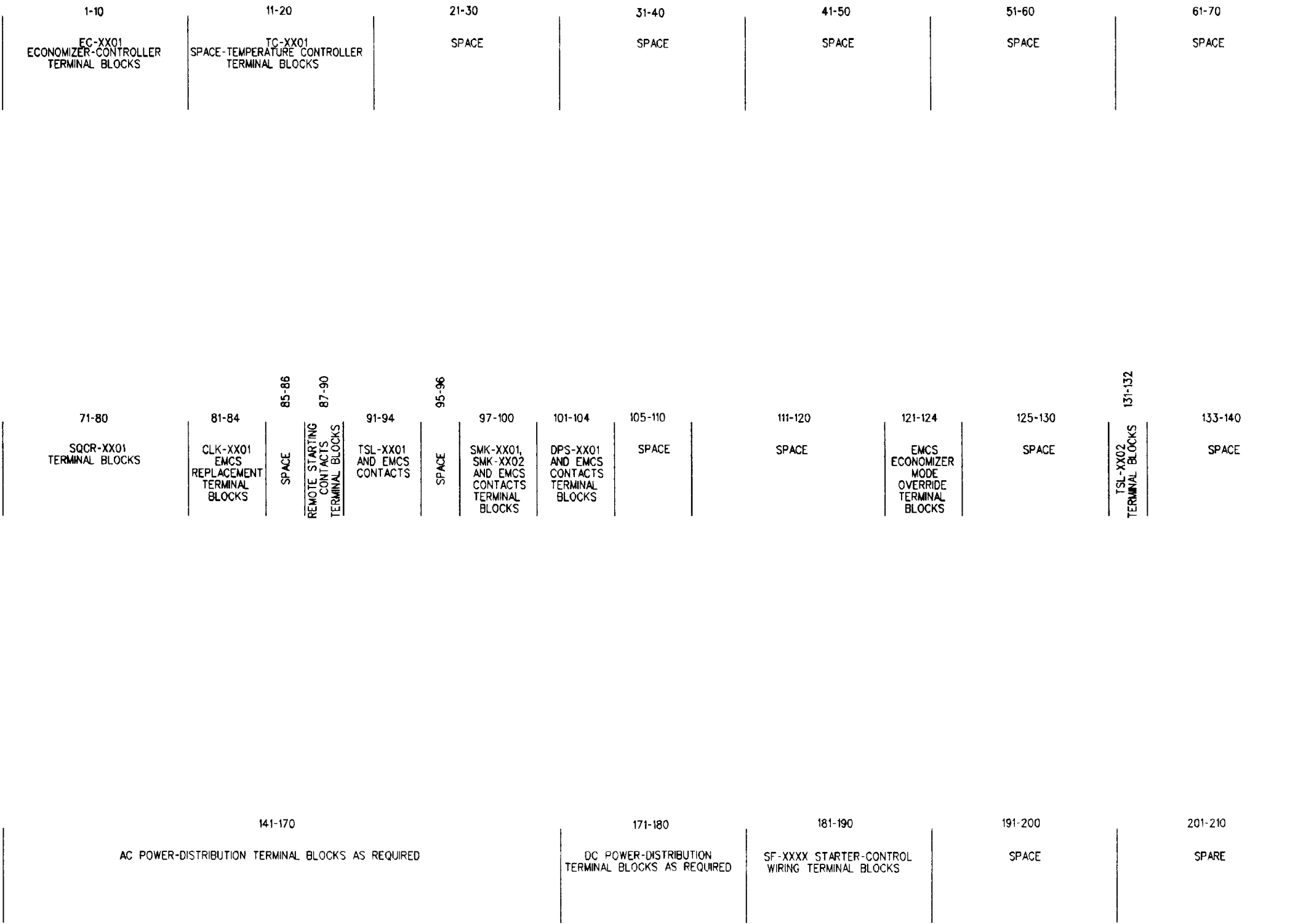


Figure 4-22F. Terminal-block layout for DX-coil single-zone HVAC system XX control panel.

Chapter 5

Control-System Design Variations

5-1. General

The control systems shown in chapter 4 will be modified when required to account for HVAC-system equipment variations. The variations covered in this chapter are as follows:

- a. 100-percent outside-air systems.
- b. Control of exhaust fans.
- c. Smoke dampers.
- d. Variable-speed drives.
- e. Steam-preheat coil with face-and-bypass dampers.
- f. Modulating hot-water or hot-glycol preheat coil.
- g. Combining hydronic-control systems and air-control systems in the same HVAC-control panel.
- h. Unoccupied-mode space-temperature setback control for terminal units.
- i. Two-way shut-off valves on fan-coil units.
- j. EMCS-initiated building-purge and recirculation modes.
- k. Smoke control and freeze protection.
- l. Control systems without economizer modes.
- m. *Dual steam valves.*

5-2. Control-system variations for 100-percent outside air (continuous operation)

- a. HVAC systems that introduce 100-percent outside air are used as air-makeup systems when large quantities of air are exhausted from the space. Such systems are used in the heating and cooling of such spaces as hospital operating rooms and laboratories, which cannot recirculate air from the space through the system. Spaces that cannot use return air will usually have more air exhausted than is supplied, to insure that the space is at a negative pressure with respect to surrounding spaces. This may be accomplished by an exhaust fan interlocked with the supply fan.
- b. A 100-percent outside-air system does not require the economizer-changeover and mixed-air-temperature control loops, but does require an outside-air preheater coil and associated temperature-control loop in most climates.
- c. The 100-percent outside-air system may need a humidifier and its control loop. This loop would function identically as discussed in paragraph 3-8 and shown in figure 3-12.
- d. Figure 5-1 shows the variations that would occur for a 100-percent outside-air unit. The outside-air preheat coil may be a heat-recovery coil, which may be part of a glycol run-around system that recovers heat in the air from one or more exhaust fans. The heating coil will not be part of the recovery system. The system shown in figure 5-1 has a temperature/humidity control sequence as described in chapter 4. If the system has a heat-recovery coil, some additional controls may be required if they are not part of a total heat-recovery package. The exhaust fan is shown with a pneumatic damper actuator. Device EP-XX02 is shown as field-mounted, but it may be located in a local

fan starter or may be included in the HVAC control panel. The designer will make this choice.

e. The ladder diagram variations for the 100-percent outside-air system are shown in figure 5-2, which is similar to figure 4-21B, but modified to delete the relay and pilot lights associated with the ventilation-delay mode and with the system stops during the unoccupied mode. A smoke detector is required in the supply-fan discharge. Figure 5-2 shows an exhaust-fan section of the ladder diagram on lines 300 through 303. Each interlocked exhaust fan requires a contact of R-XX02 for safety shutdown and a remote safety override, located at assigned terminal blocks in the HVAC control panel.

5-3. Control-system variations for exhaust fans

- a. Schematic variations for an exhaust fan are shown in figure 5-3, for electric and pneumatic actuators. Solenoid 3-way air valve EP-XX02 and damper actuator DA-XX02 will be energized to open their respective dampers when their respective fans start. These devices will be powered from a source other than the starter transformer, such as the HVAC control panel.
- b. Ladder-diagram variations for exhaust fans are shown in figure 5-4. These variations are somewhat different from the exhaust-fan interlock shown in figure 5-2, which are intended for exhaust fans that are interlocked to HVAC systems handling return air. One exhaust-fan example is shown with a pneumatic damper operator, for guidance in applying pneumatic actuators to shutoff dampers. No positive positioner is required for the actuator. In this example, the fan is off and the dampers are closed in the unoccupied and ventilation-delay mode. Another example is shown with an electric damper actuator, for guidance in applying electric actuators to shutoff dampers. In this example, the dampers are open whenever the supply fan runs. The designer will add relays in parallel with R-XX01, R-XX03, and R-XX11, as required to accommodate contacts to control additional exhaust fans. The designer will show contact and coil references on the schematic and the ladder diagram for the additional relays.
- c. The designer will check the exhaust-fan selection for the rated shutoff static pressure to determine whether a damper end switch should be applied to the control of the exhaust-fan starter circuit. If the shutoff static pressure is 1 inch of water column or higher, the designer will incorporate an end switch in the design as described later in this manual under variations for smoke dampers.

5-4. Control-system variations for smoke dampers

- a. Smoke dampers can be used with any HVAC air-delivery system, but generally the smoke dampers are required only when the HVAC unit exceeds a given air capacity. An example of the use of smoke dampers is shown in figure 5-5. Actuators DA-XX04 and DA-XX05 will be powered from some source other than the fan-starter holding-coil transformer, such as the HVAC control panel. The contacts of relays R-XX13 and R-XX14 both must be closed to allow any smoke dampers to open.
- b. Figure 5-6 shows the ladder-diagram variations for

smoke dampers. When relay-coil R-XX13 on line 105 is energized, contacts in the power circuits to DA-XX04 and DA-XX05 are closed. Similarly, when relay-coil R-XX14 on line 205 is energized, contacts in these same circuits are closed. When both relays are energized, actuators DA-XX04 and DA-XX05 open their respective smoke dampers. When the smoke dampers open, end switches ES-XX01 and ES-XX02 close their contacts on line 20 to energize relay-coil R—XX12. When relay-coil R-XX12 is energized, contacts on lines 104 and 204 close, to allow starter-holding coils M01 and M02 to energize and start the fans. Tripping either end switch will shut down both fans. Relay coils R-XX11 and R-XX12 are the only devices that will be powered from the starter-holding-coil transformers. The relays must be wired through the overload relay contacts and must be powered in the “HAND” and “AUTO” positions of the “HAND-OFF-AUTO” switch; they also must be powered in the event that the remote-safety-override circuit is closed. Both dampers must open before either fan can start, and each must close when its respective fan is stopped.

c. The designer will modify HVAC control-panel layouts to show the relays and terminal blocks associated with these variations.

5-5. Control-system variations for variable-speed drives

- a. Figure 5-7 shows variable-speed drives in lieu of the supply and return-fan inlet vanes. Relay contacts in the supply-duct static-pressure control loop and the return-fan-volume control loop, which open on supply-fan shutdown, are not necessary because there are no inlet vanes.
- b. The variable-speed drive must accept a 4 to 20 milliamperes signal as an input.
- c. Figure 5-8 shows the ladder-diagram variations for variable-speed drives. It shows connections to the variable-speed-drive control circuits in lines 100 and up and in lines 200 and up. There is no magnetic starter in this case, because all starter functions are provided by the variable-speed-drive controller.
- d. Figure 5-9 shows variable-speed drives in lieu of actuators for the inlet vanes.
- e. Figure 5-10 shows the variations in the control-panel interior-door layout for variable-speed drives. There are no receiver gauges in the interior door, because IPs for the inlet vanes are not required.
- f. Figure 5-11 shows the variations in the back-panel arrangements for variable-speed drives, with the bulkhead fittings for control of the dampers and the cooling-coil valve. There is no need for bulkhead fittings for control of inlet vanes.
- g. The terminal-block layout will show terminals assigned to the variable-speed drive units rather than for the magnetic-starter circuits for fans.

5-6. Control-system variations for steam-preheat coil with face-and-bypass damper

- a. The schematic-diagram and ladder-diagram additions to incorporate control for this type of preheat coil

are shown in figure 5-12. The steam coil valve, VLV, is controlled from a 2-position thermostat, TSL, in the incoming outside-air duct. The thermostat opens the steam valve when the outside-air temperature drops to its setpoint and remains open as long as the outside-air temperature is at or below the setpoint. The loop consisting of devices TT, TC, IP, and DA controls the air temperature in the discharge of the coil by modulating the preheat-coil face-and-bypass damper to maintain the preheat-coil discharge-air temperature.

b. Thermometer TI in the outside-air intake is required if there is not already such a device at an outside-air temperature transmitter associated with an economizer controller.

c. The control devices and their parameters must be added to the equipment schedule.

5-7. Control-system variation for hot-water or hot-glycol preheat coil

The loop to be added to control-system schematics for modulating control of such preheat coils is as discussed in paragraph 3-3 and shown in figure 3-2. When required, this loop can be added to any HVAC system by showing the loop in the control-system schematic, showing the loop devices and their parameters in the equipment schedule, and showing the controller and related devices in the control-panel drawings.

5-8. Control-system variation for combining hydronic-system and air-system controls in the same control panel

This variation is shown in chapter 4 in the single-zone HVAC-system with humidity control. Small buildings generally require a hydronic-heating system or a dual-temperature water system and an air-handling system. When appropriate, the designer will combine such systems into a common HVAC control panel.

5-9. Unoccupied-mode space-temperature setback control for terminal units

In chapter 4, the control systems for unit heaters and perimeter radiation are shown with room thermostats capable of one temperature setting. When the hydronic systems serving such units are controlled to maintain a reduced space temperature in the unoccupied mode, a microprocessor-based room thermostat will be substituted for the single-temperature thermostat shown in chapter 4. An example of the substitution is shown in figure 5-13.

5-10. Control-system variations for 2-way shut-off valves for fan-coil unit

For dual-temperature hydronic systems with variable-flow pumping, the fan-coil units will have 2-way shut-off valves in lieu of 3-way shutoff valves. The designer may show 3-way shut-off valves on selected fan-coil units for pump relief of the variable-flow pumping system. The schematic and ladder diagram variations are shown in figure 5-14.

5-11. Control-system variations for EMCS-initiated building-purge and recirculation modes

- a. When EMCS requires control of HVAC-system outside-air, return-air, and relief-air dampers, the devices used by EMCS to assume control of the dampers are external to the HVAC control panel. The devices required depend on whether the actuators are pneumatic or electric/electronic.
- b. Figure 5-15 shows the schematic variation for pneumatic actuators. The EMCS devices are: EPs labeled “EMCS”, the purge-auto and recirculating/auto contacts, and the associated control circuit. When EMCS is not in control, and EPs pass the pneumatic control signal from IP-XX01 to the PPs of the damper actuators. When the “PURGE/AUTO” contact is closed, main air passes through EP-I to the PPs of the dampers, which causes the outside-air damper to fully open. When the “RECIRCULATING/AUTO” contact is closed, air is exhausted from the damper-actuator PPs, causing the outside-air damper to close. The return-air and relief-air dampers normally work in concert with the outside-air damper. When both EMCS contacts are open, the EPs are de-energized and IP-XX01’s pneumatic-control signal is connected to the damper actuator’s PPs.
- c. Figure 5-16 shows EMCS devices required when the damper actuators are electric or electronic. The relays labelled “R-1 EMCS” and “R-2 EMCS” function in a manner similar to the EPs required for pneumatic

actuators. The device labelled “EMCS MPS” is a minimum-position switch set to hold the outside-air damper open in the purge mode. The signal to the actuators is interrupted in the recirculating mode to close the outside-air damper.

5-12. Control-system variations for smoke control and freeze protection

In addition to the required HVAC control panels already shown, an HVAC system may have a smoke-control and freeze-protection panel, to house the equipment required to connect these systems to the HVAC control system. These systems can interrupt the control signals to starters, valves, and dampers for these special purposes. The smoke-control and freeze-protection panels, if required, will be custom-designed specifically for each project. The standard HVAC control panels have interface provisions at terminal blocks for smoke-control systems, freeze-protection systems, or other external systems designed either to shut down the HVAC system or to bypass the shutdown circuits of the HVAC control system as required. The contract documents must show the interface requirements and locations of each non-H VAC control panel in the project.

5-13. Control-system variations for non-economizer HVAC systems.

- a. The economizer mode of operation is not

appropriate for every HVAC application. When an HVAC system is designed for comfort applications without humidity control (i.e., no humidification or dehumidification), the control system will have a minimum-position switch to allow some adjustment of the mixed-air flow. The steps involved in modifying a standard single-zone economizer-mode control system (such as shown in chapter 4) to convert it to a non-economizer control system are:

- (1) Delete all economizer-loop devices (such as the economizer controller and its transmitter, relay contacts, and signal selector) from the control-system schematic.
- (2) Delete the economizer’s PV and DEV contacts and their associated relay and pilot light from the ladder diagram.
- (3) Delete the economizer controller and associated devices from the equipment schedule.
- (4) Delete the economizer controller from the interior-door layout.
- (5) Delete the signal selector and relays associated with the economizer controller from the back-panel layout.
- (6) Delete the economizer-controller terminals from the terminal-block layout.

- b. Control systems other than a single-zone control system can be modified to delete the economizer mode by deleting additional devices as follows:

- (1) Delete the mixed-air temperature control loop and associated devices from the schematic.
- (2) Delete the mixed-air temperature controller and associated devices from the equipment schedule.
- (3) Delete the mixed-air temperature controller from the interior-door layout.
- (4) Delete the mixed-air temperature controller terminal blocks from the terminal-block layout.
- c. To show the results of the previously-described procedures, the single-zone system shown in figures 4-19A through 4-19F has been modified to show a single-zone, non-economizer control system as figures 5-17A through 5-17F.

5-14. Control systems with dual-steam valves

Generally when the size of a steam-service control valve exceeds 2½ inches (pipe size), two steam valves will be used; the valve C_v will be selected from available products with one valve having a smaller C_v. The valves are sequenced without a control-signal deadband. The control-signal range available for operating the valves will be split into two equal parts. In the control sequence, the smaller control valve opens first. The control-system drawings affected are the schematic and the equipment schedule. Figures 4-10A and 4-10C have been modified to show the required changes and are shown as figures 5-18 and 519.

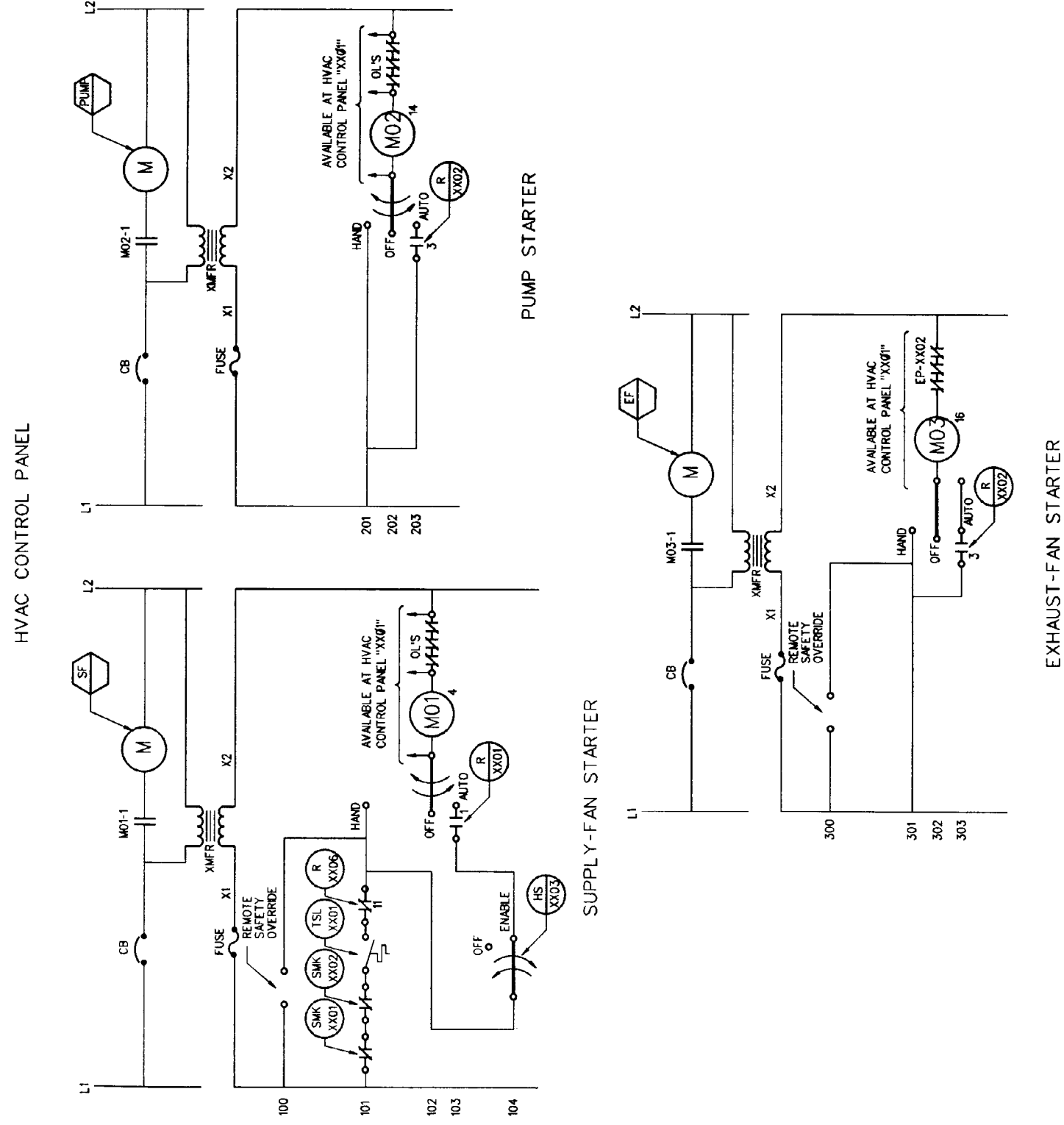
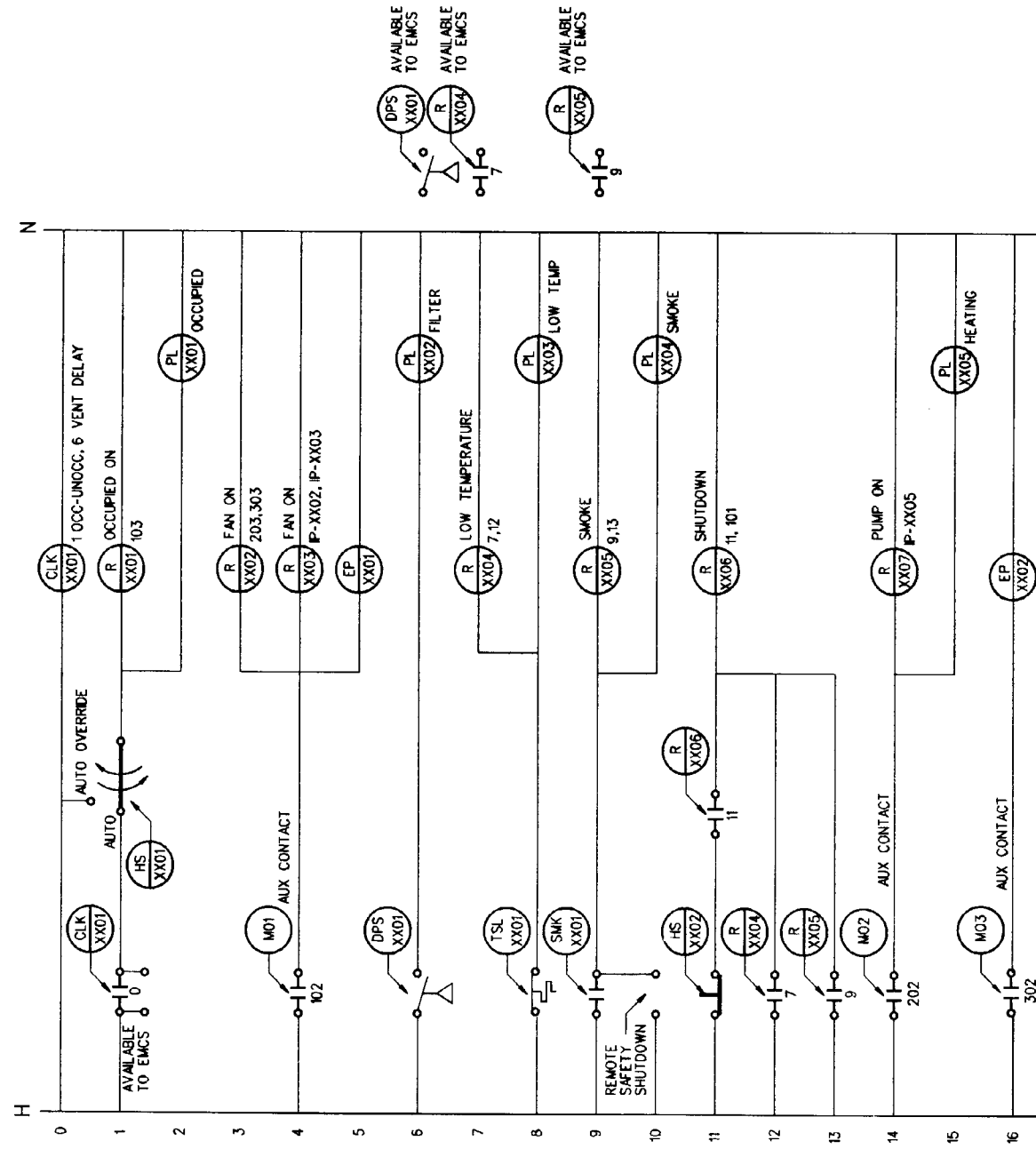
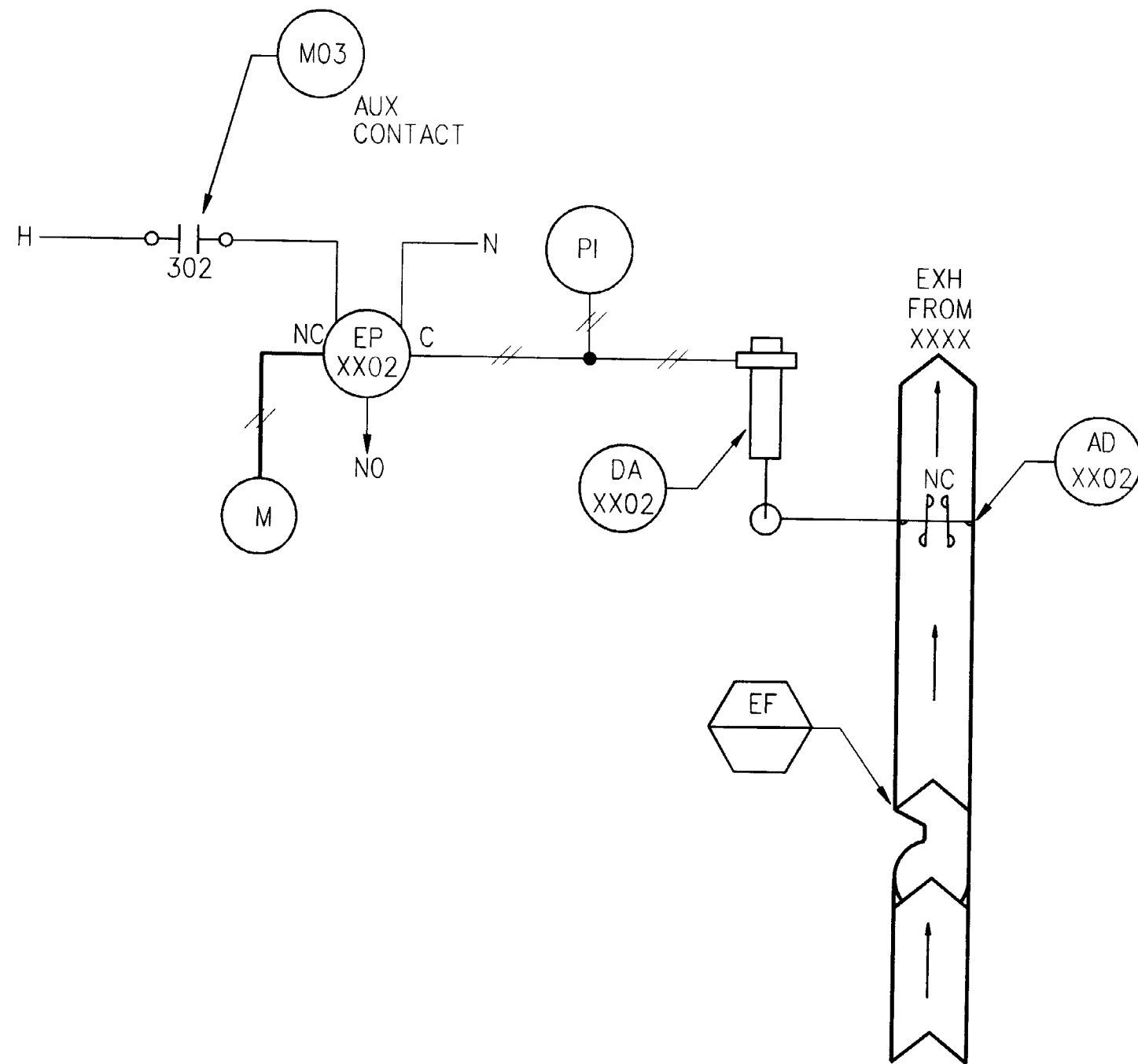
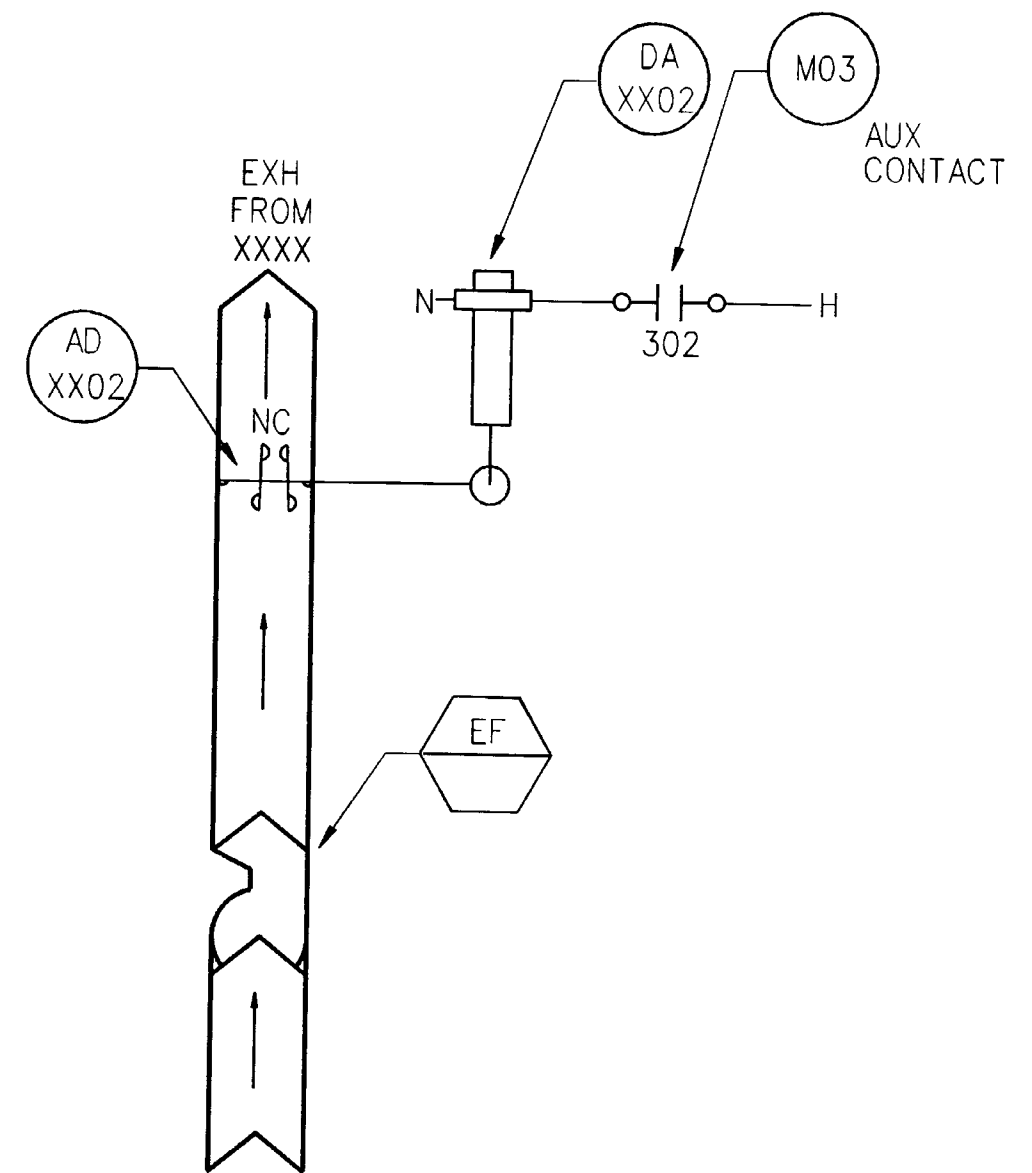


Figure 5-2. Ladder-diagram variations for 100-percent outside-air systems.



PNEUMATIC-DAMPER ACTUATOR



ELECTRIC-DAMPER ACTUATOR

Figure 5-3. Schematic variations for exhaust fans.

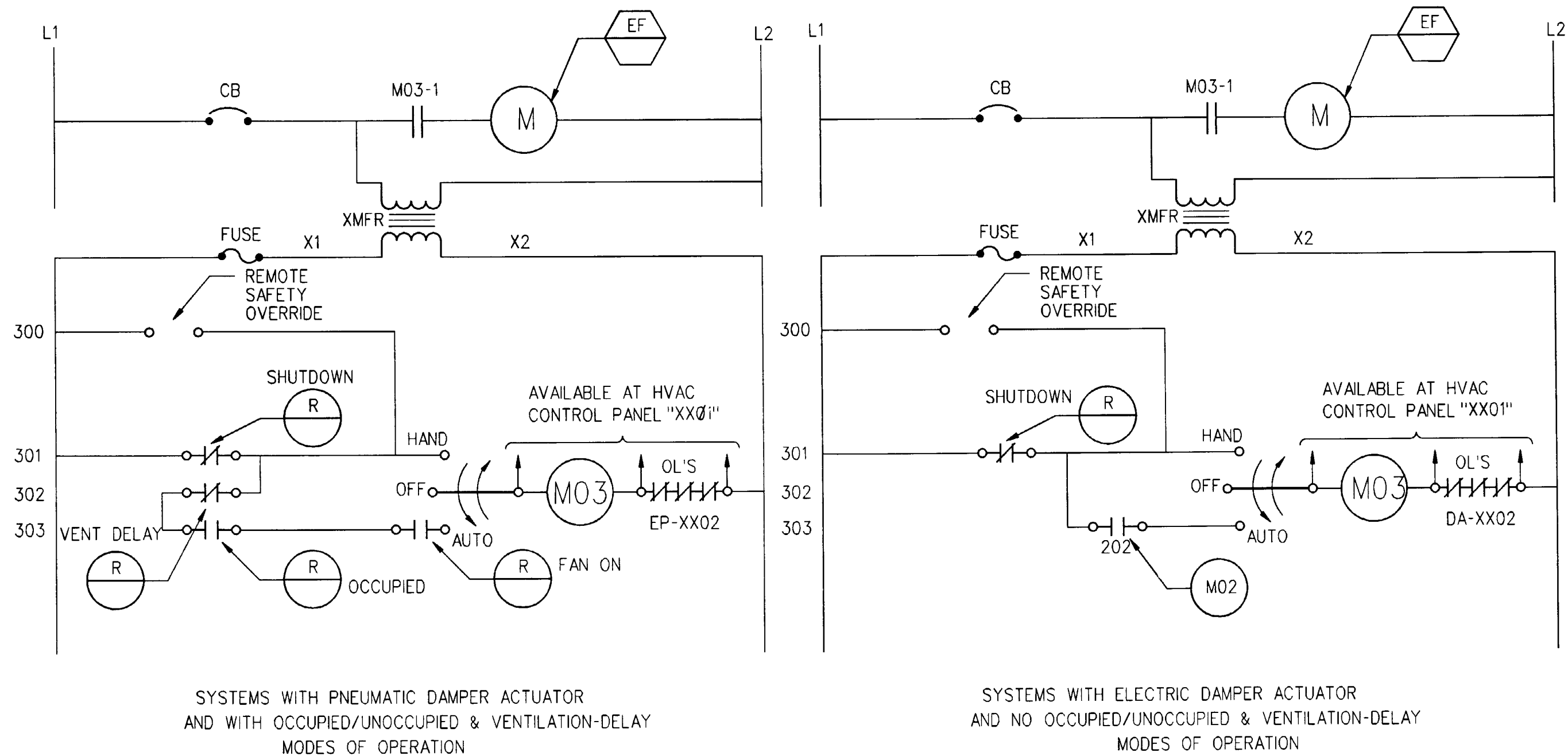


Figure 5-4. Ladder-diagram variations for exhaust fans.

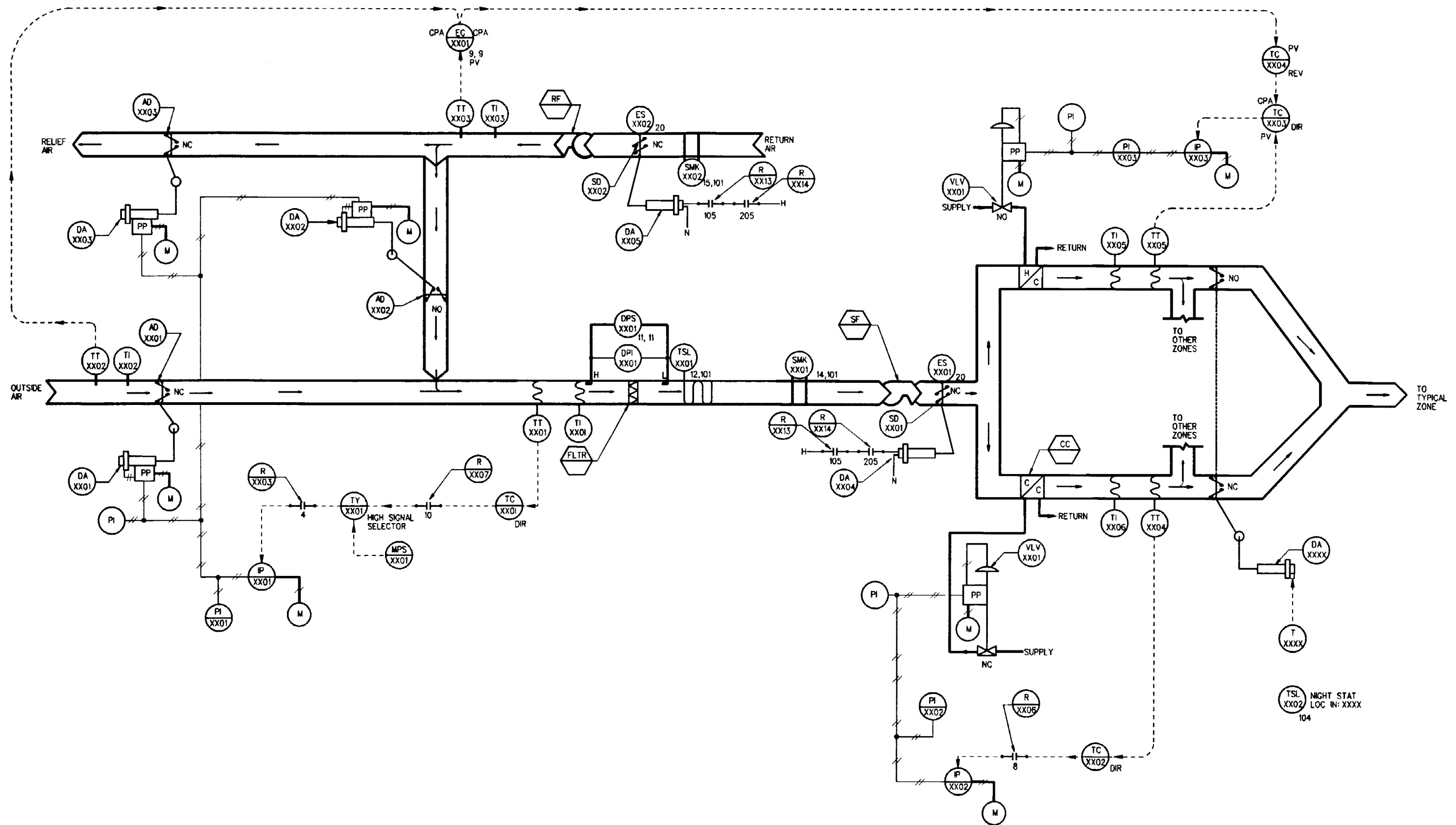
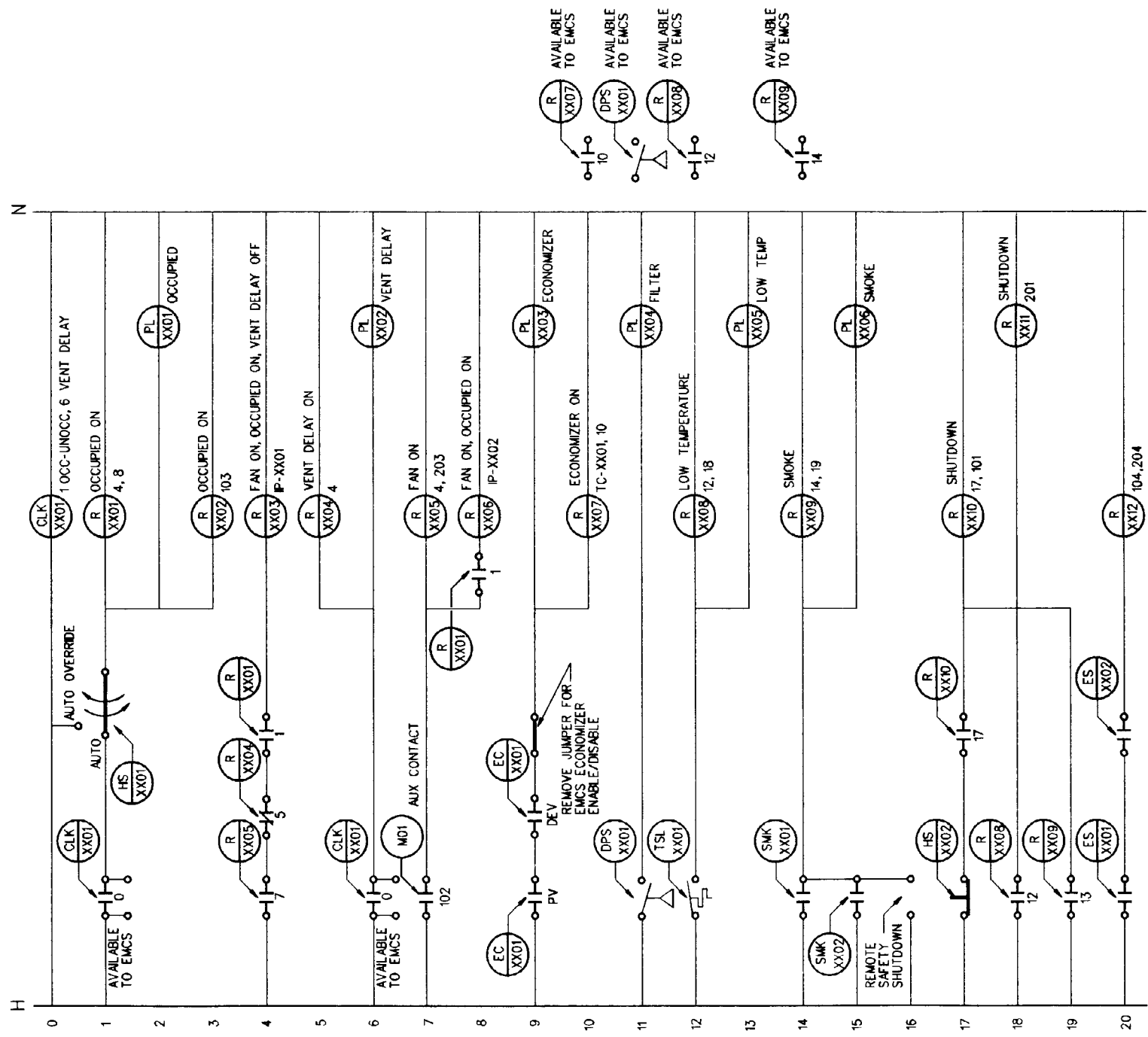


Figure 5-5. Schematic variations for smoke dampers.



HVAC CONTROL PANEL

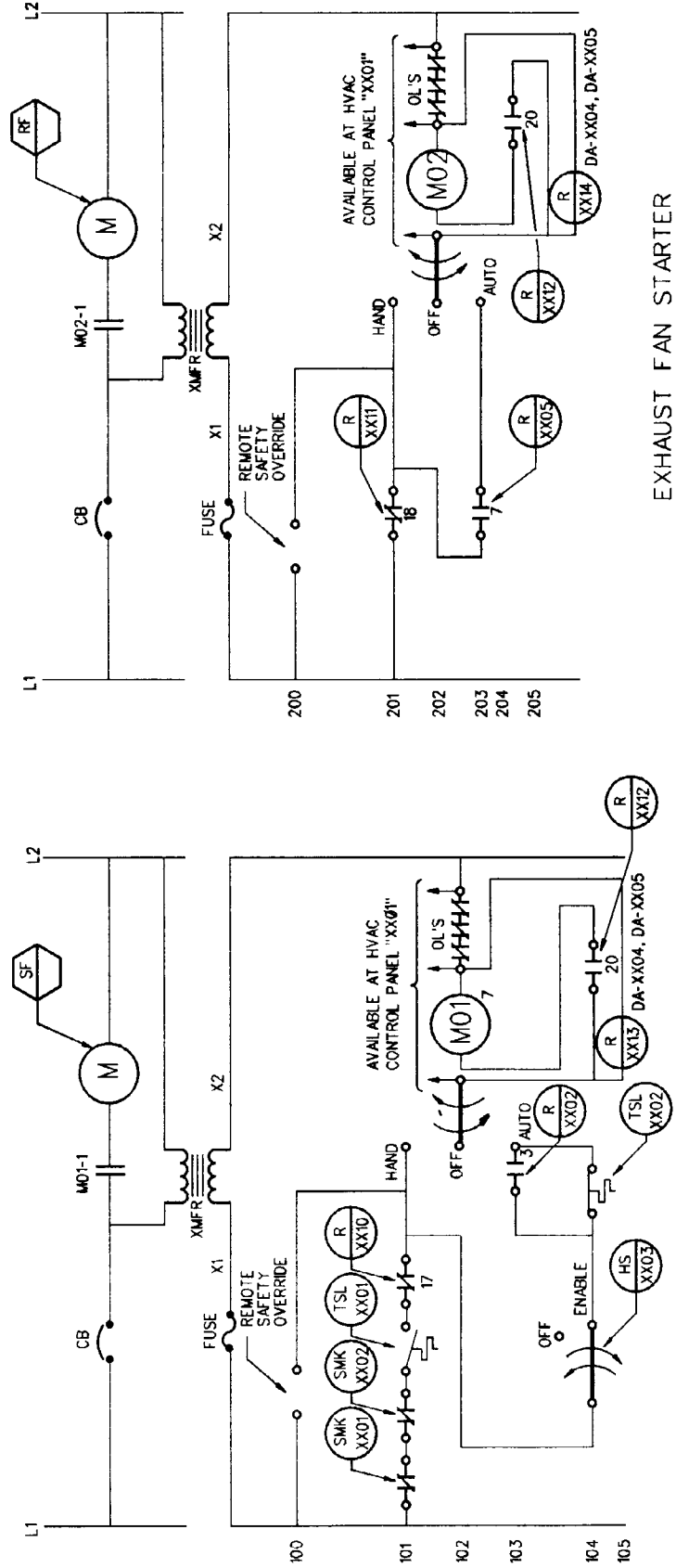


Figure 5-6. Ladder-diagram variations for smoke dampers.

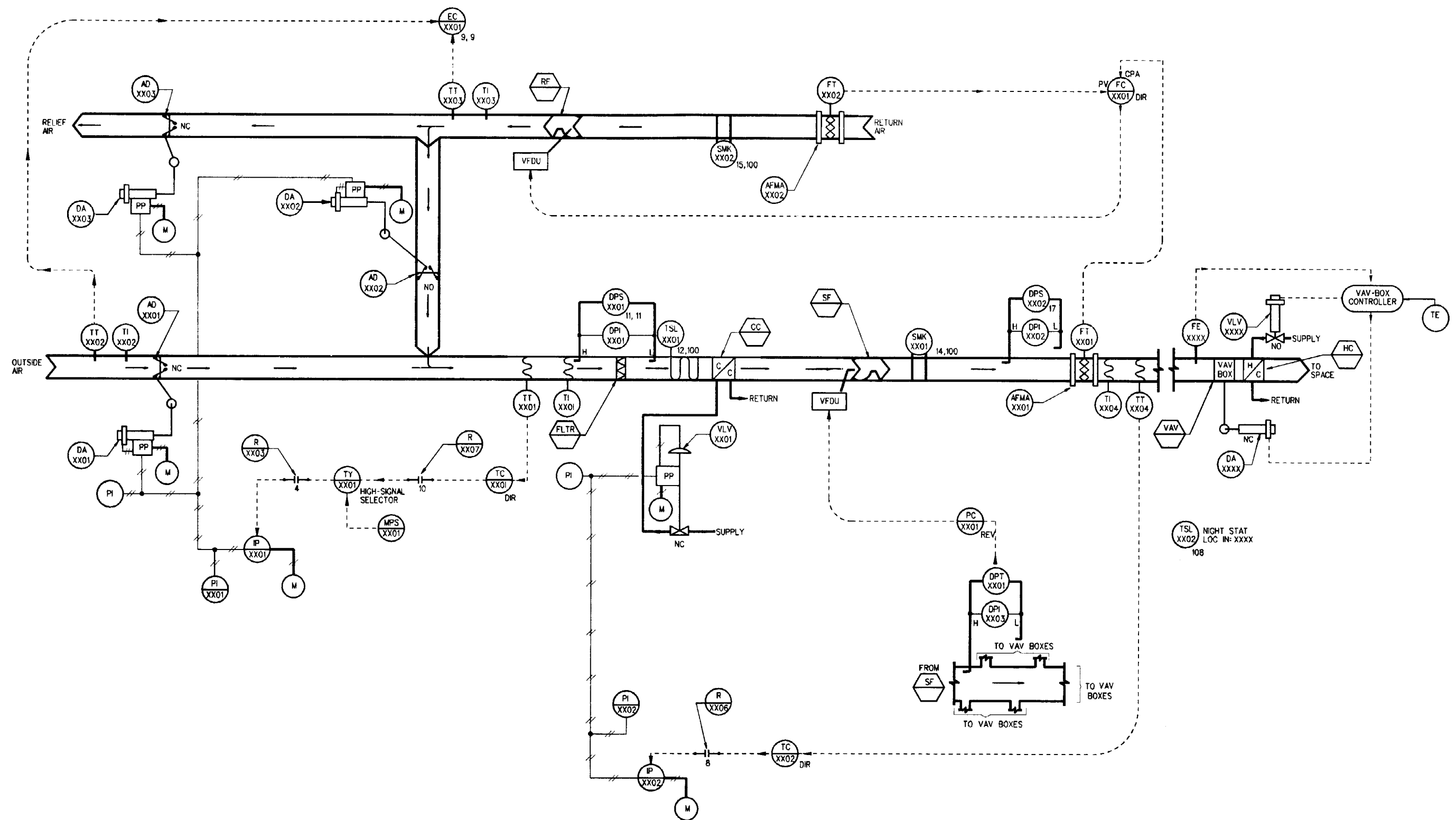


Figure 5-7. Schematic variations for variable-speed drives.

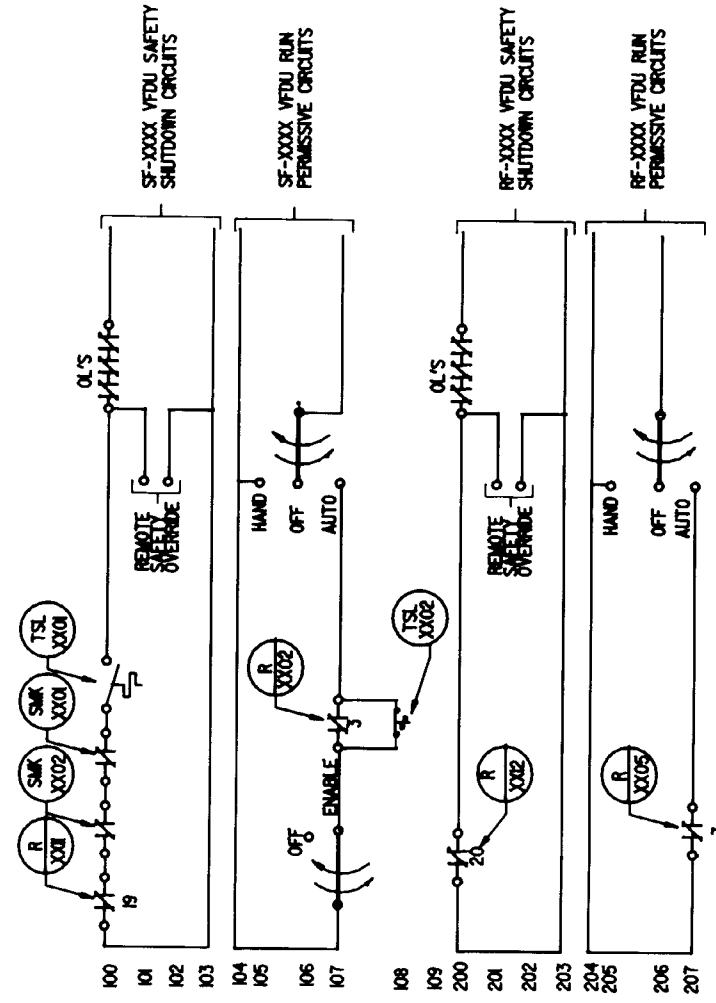
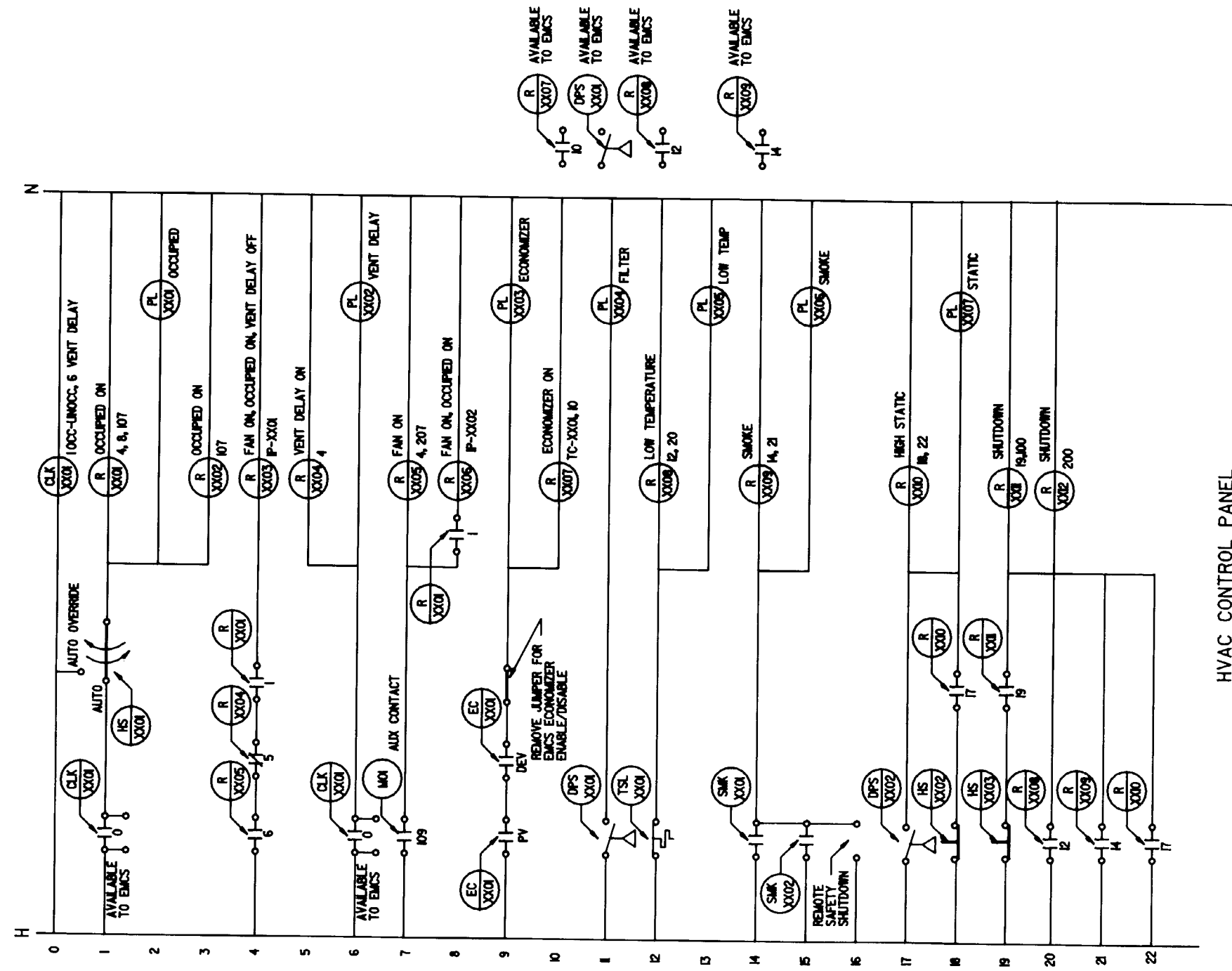
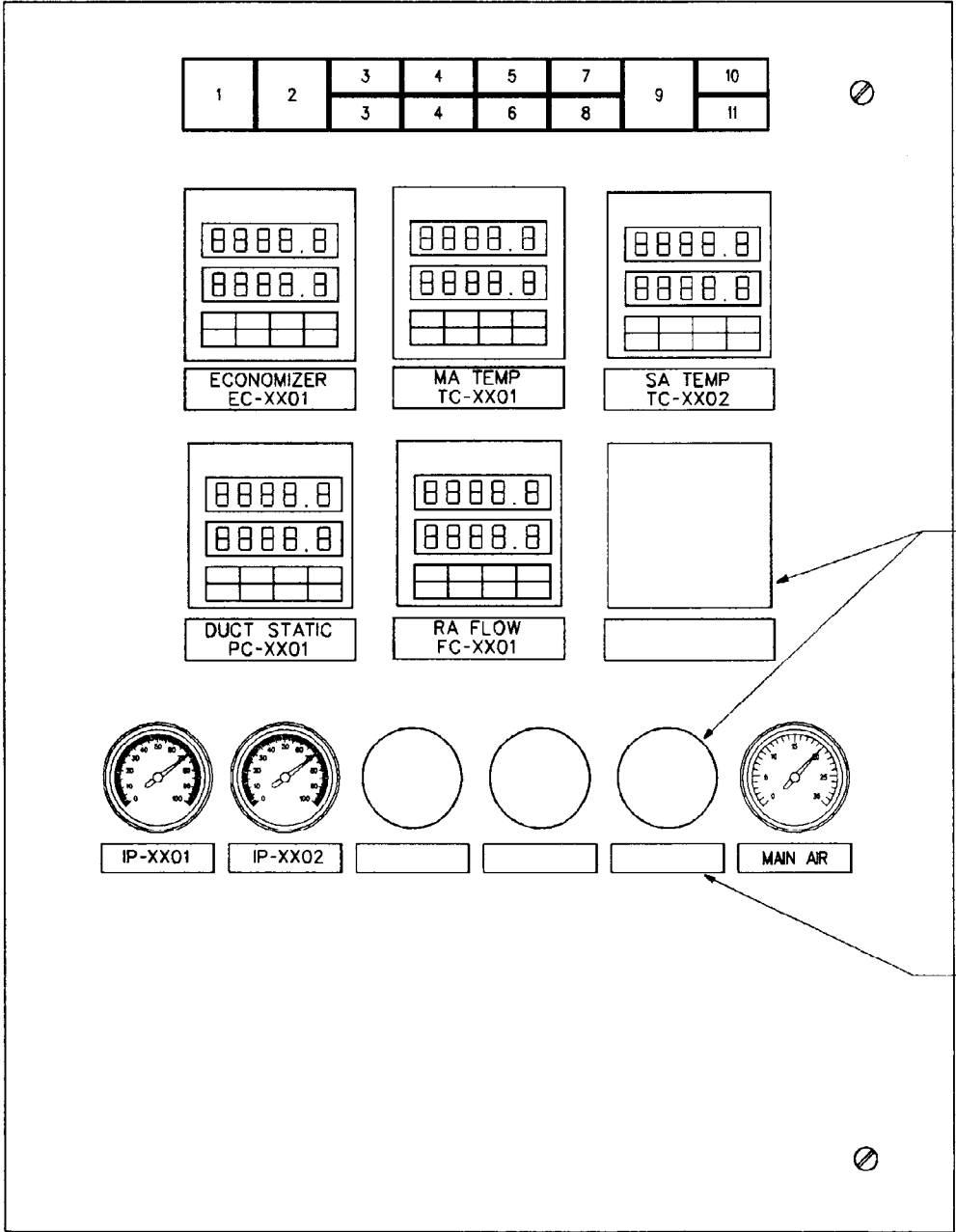


Figure 5-8. Ladder-diagram variations for variable-speed drives.

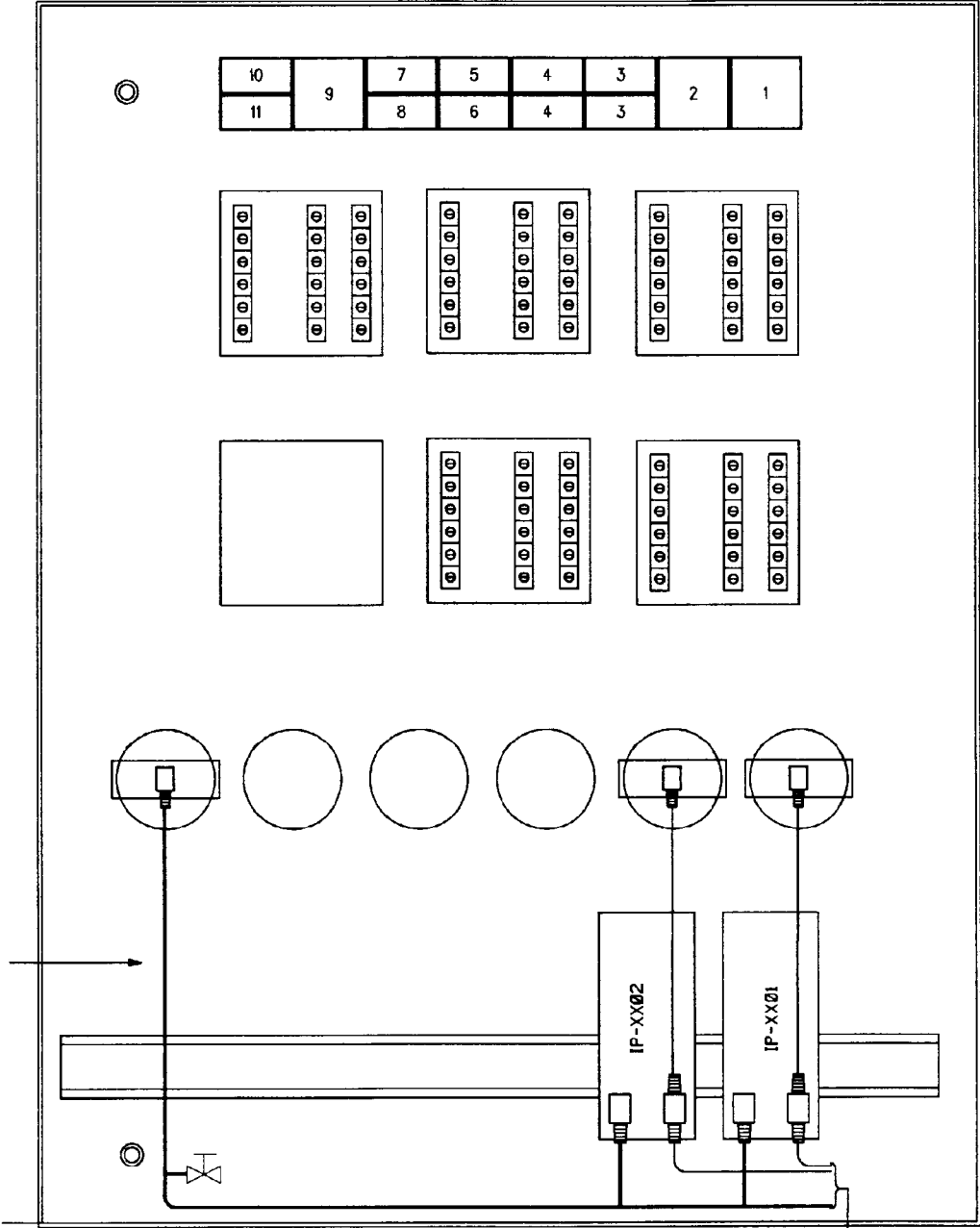
LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
MIXED-AIR TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	3-15 PSIG	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM AT MAXIMUM SUPPLY FAN TURN DOWN
	TC-XX01	MIXED-AIR TEMPERATURE CONTROLLER	55°F	40° TO 140°F	—
	TT-XX01	MIXED-AIR TEMPERATURE TRANSMITTER	—	40° TO 140°F	—
	TT-XX02	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130 °F	—
	TT-XX03	RETURN-AIR TEMPERATURE TRANSMITTER	—	-30 TO +130 °F	—
	EC-XX01	ECONOMIZER CONTROLLER	—	PV CONTACT CLOSE AT 73°F OPEN AT 71°F	DEV CONTACT CLOSE WHEN ΔT=8 °F OPEN WHEN ΔT=6 °F
	AT-XX01	LOW-TEMPERATURE SWITCHOVER	40°F	OPEN AT 40°F CLOSE AT 42°F	—
	TSL-XX01	LOW-TEMPERATURE PROTECTION THERMOSTAT	35°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	LOW-LIMIT SPACE-TEMPERATURE THERMOSTAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
DISCHARGE-AIR TEMPERATURE	VLV-XX01	COOLING-COIL VALVE	—	3-15 PSIG	CV=20 CLOSE AGAINST 20 PSIG
	TC-XX02	FAN-DISCHARGE TEMPERATURE CONTROLLER	57°F	0-100°F	—
	TT-XX04	FAN-DISCHARGE TEMPERATURE TRANSMITTER	—	0-100°F	—
SUPPLY-DUCT STATIC PRESSURE	PC-XX01	SUPPLY-DUCT STATIC PRESSURE CONTROLLER	1.2 INCHES WATER	0.0-2.0 INCHES WATER	—
	DPT-XX01	SUPPLY-DUCT STATIC PRESSURE TRANSMITTER	—	0.0-2.0 INCHES WATER	—
RETURN/RELIEF-FAN VOLUME	FC-XX01	RETURN-FAN VOLUME CONTROLLER	SUPPLY FAN CFM MINUS 3000 CFM	0-20,000 CFM	—
	FT-XX01	SUPPLY-DUCT FLOW-RATE TRANSMITTER (FPM)	—	0-20,000 CFM	—
	FT-XX02	RETURN-RELIEF DUCT FLOW TRANSMITTER (FPM)	—	0-20,000 CFM	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS, OPEN: 1700 HRS M,T,W,Th,F	OPEN: SAT, SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS, OPEN: 0800 HRS M,T,W,Th,F	

NOTE: OTHER DEVICES SUCH AS IPS, RELAYS AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 5-9. Equipment variations for variable-speed drives.



FRONT VIEW



REAR VIEW

SWITCH AND PILOT LIGHT LEGEND

POSITION LEGEND

- 1 - RESET
- 2 - STATIC RESET
- 3 - AUTO/AUTO OVERRIDE
- 4 - ENABLE/OFF
- 5 - LOW TEMP

DEVICE TYPE

- NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH
- NON-ILLUMINATED MOMENTARY PUSHBUTTON SWITCH
- ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES
- ILLUMINATED MAINTAINED CONTACT INTERLOCKED SWITCHES
- PILOT LIGHT

IDENTIFIER

- HS-XX03
- HS-XX02
- HS-XX01
- HS-XX03
- PL-XX05

POSITION LEGEND

- 6 - SMOKE
- 7 - HIGH STATIC
- 8 - FILTER
- 9 - OCC
- 10 - VENT DELAY
- 11 - ECON

DEVICE TYPE

- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT

IDENTIFIER

- PL-XX06
- PL-XX07
- PL-XX04
- PL-XX01
- PL-XX02
- PL-XX03

Figure 5-10. Interior-door-layout variations for variable-speed drives.

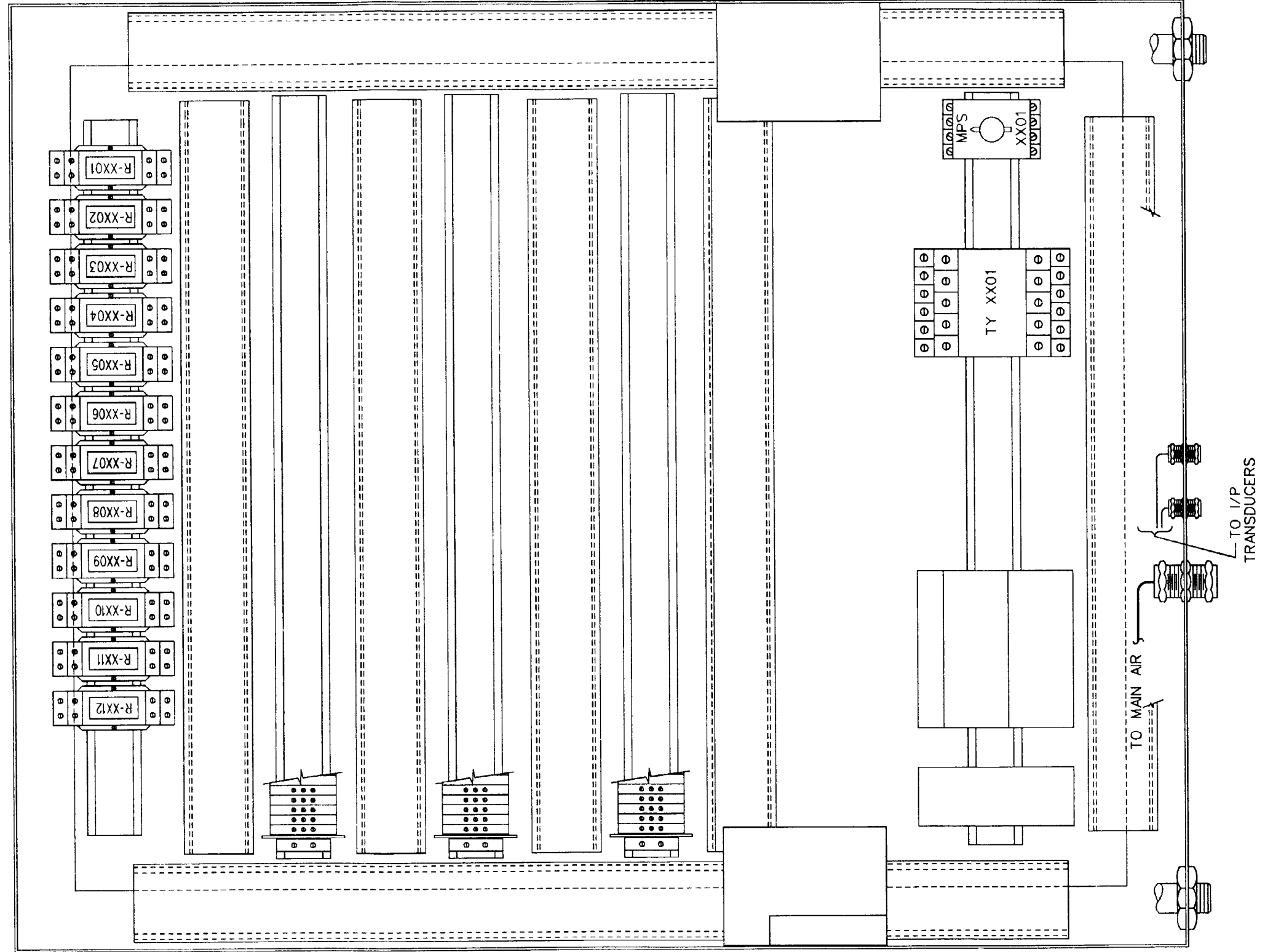


Figure 5-11. Back-panel-layout variations for variable-speed drives.

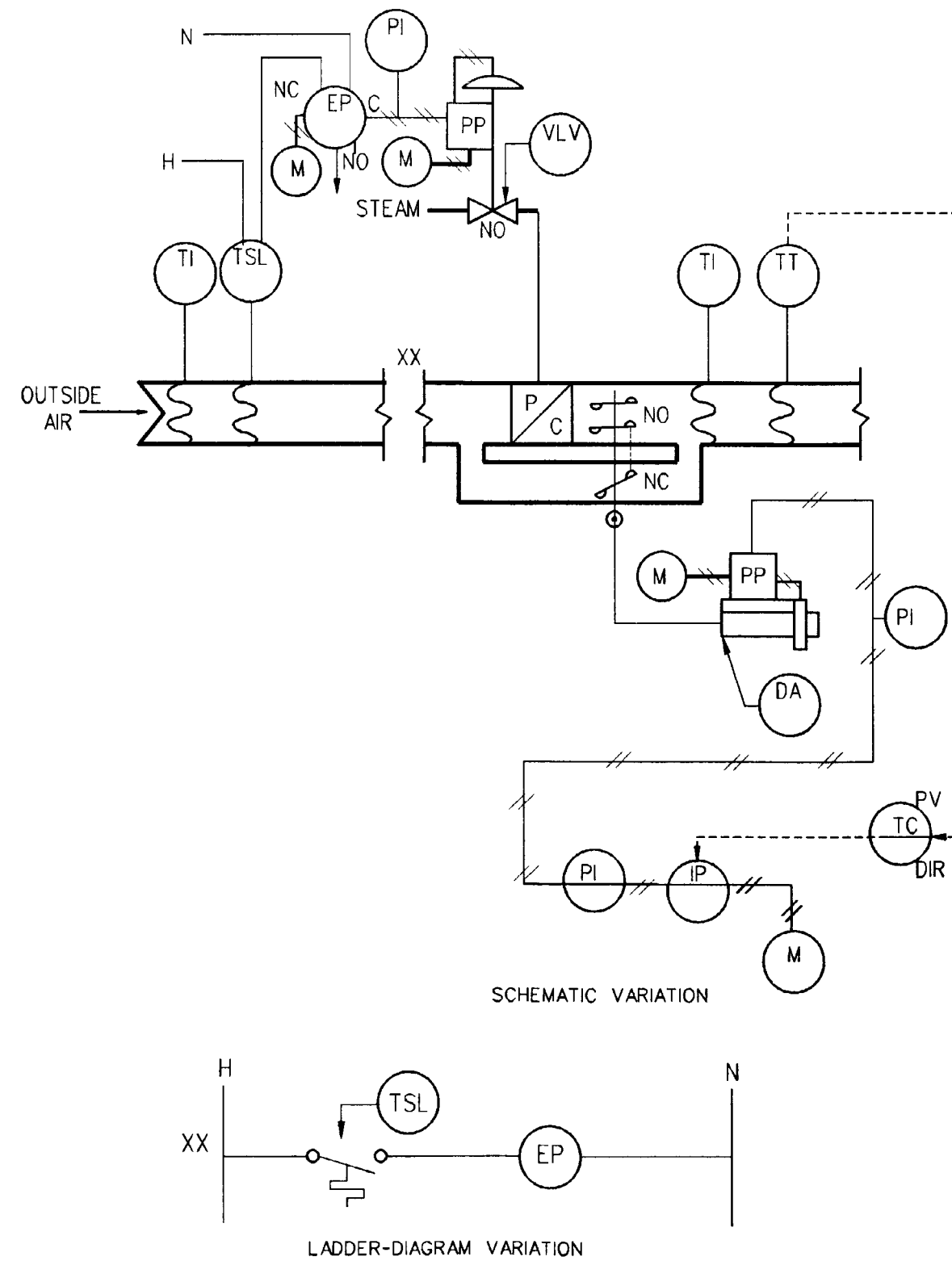
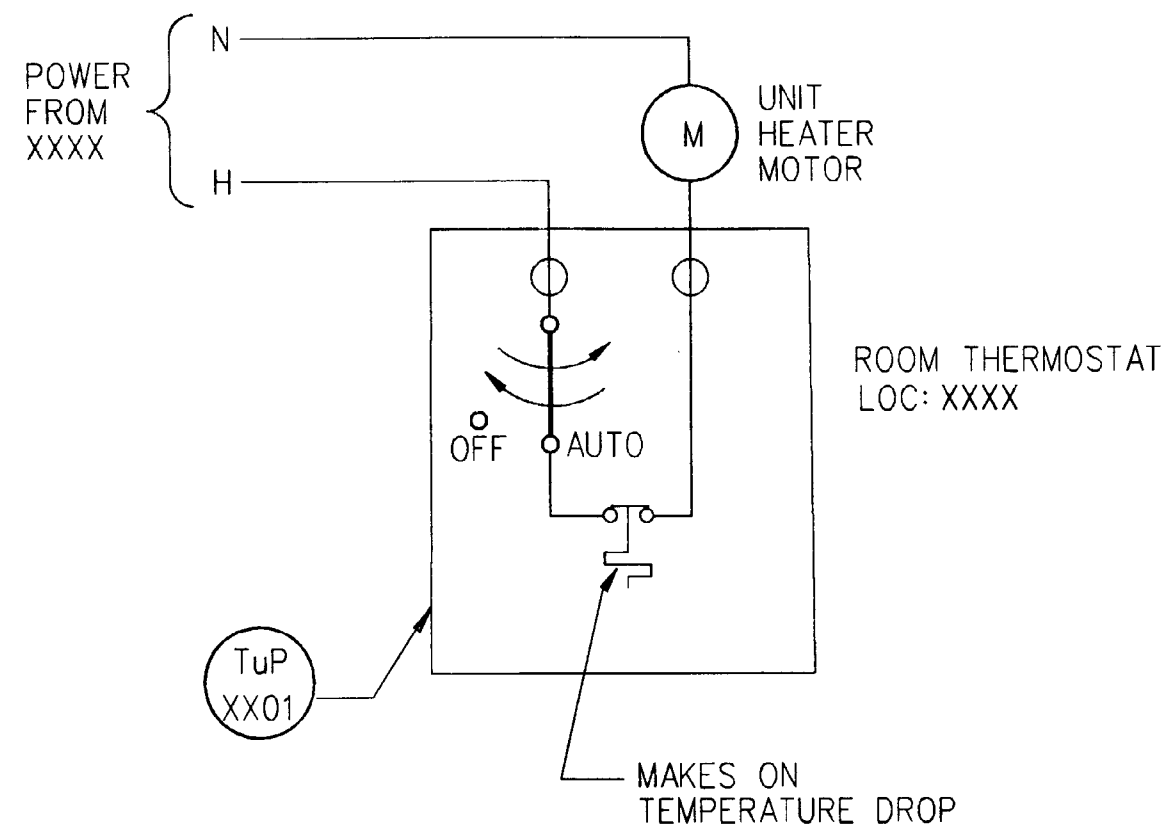
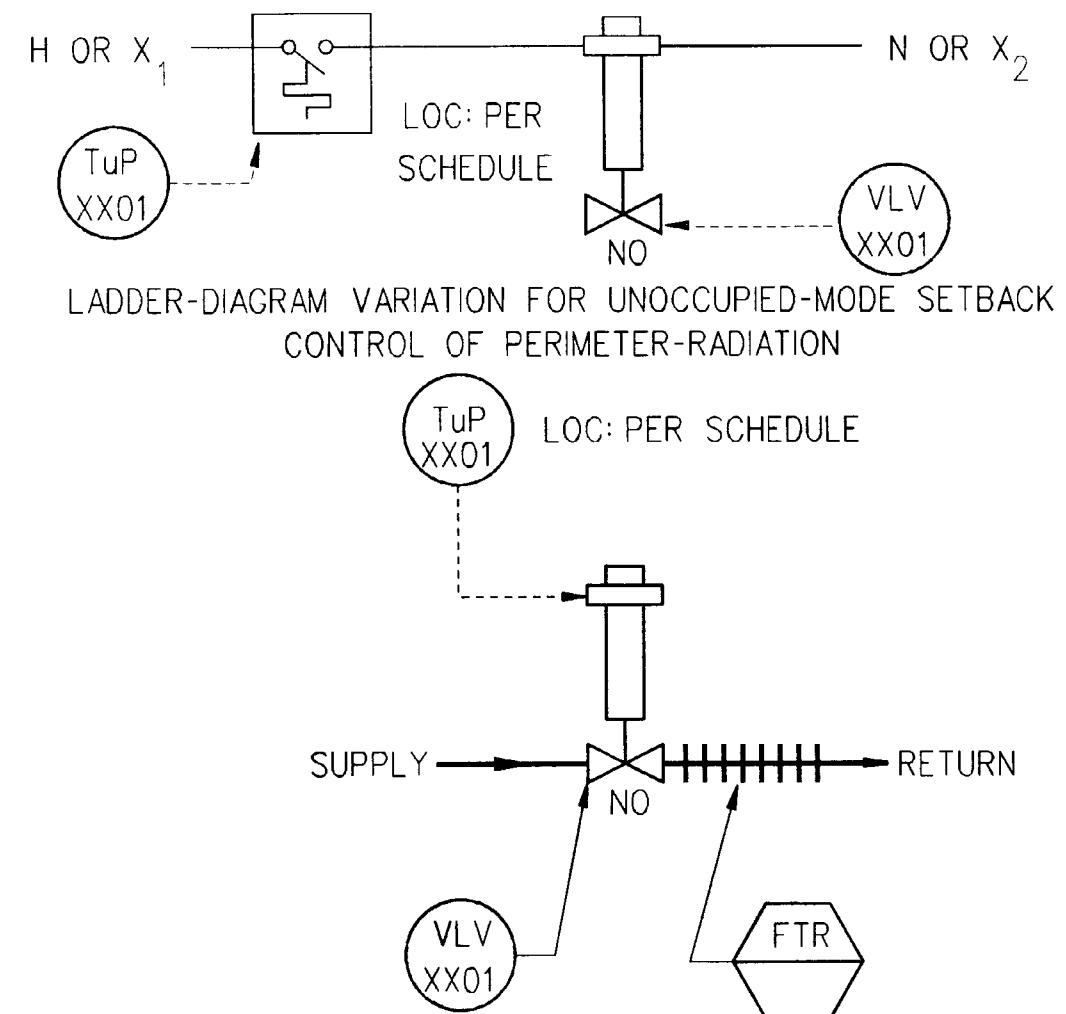


Figure 5-12. Control system variations for steam-preheat coil with face-and-bypass damper.



SPACE	UH	THERMOSTAT
XXXX	XX	TuP-XX01 SET:DAY-68°F NIGHT-55°F
.	.	.
YYYY	YY	TuP-XXXX SET:DAY-68°F NIGHT-55°F

EQUIPMENT-SCHEDULE VARIATION FOR UNOCCUPIED-MODE SETBACK
CONTROL OF UNIT HEATER



SCHEMATIC VARIATION FOR UNOCCUPIED-MODE SETBACK
CONTROL OF PERIMETER-RADIATION

SPACE	FTR	THERMOSTAT	VALVE	REMARKS
XXXX	XX	T-XX01 SET:DAY-68°F NIGHT-55°F	VLV-XX01	CV=0.2 CLOSE AGAINST 10 PSIG
.
YYYY	YY	T-XXXX SET:DAY-68°F NIGHT-55°F	VLV-XXXX	CV=0.7 CLOSE AGAINST 10 PSIG

EQUIPMENT-SCHEDULE VARIATION FOR UNOCCUPIED-MODE SETBACK
CONTROL OF PERIMETER-RADIATION

Figure 5-13. Control-system variations for unoccupied mode setback.

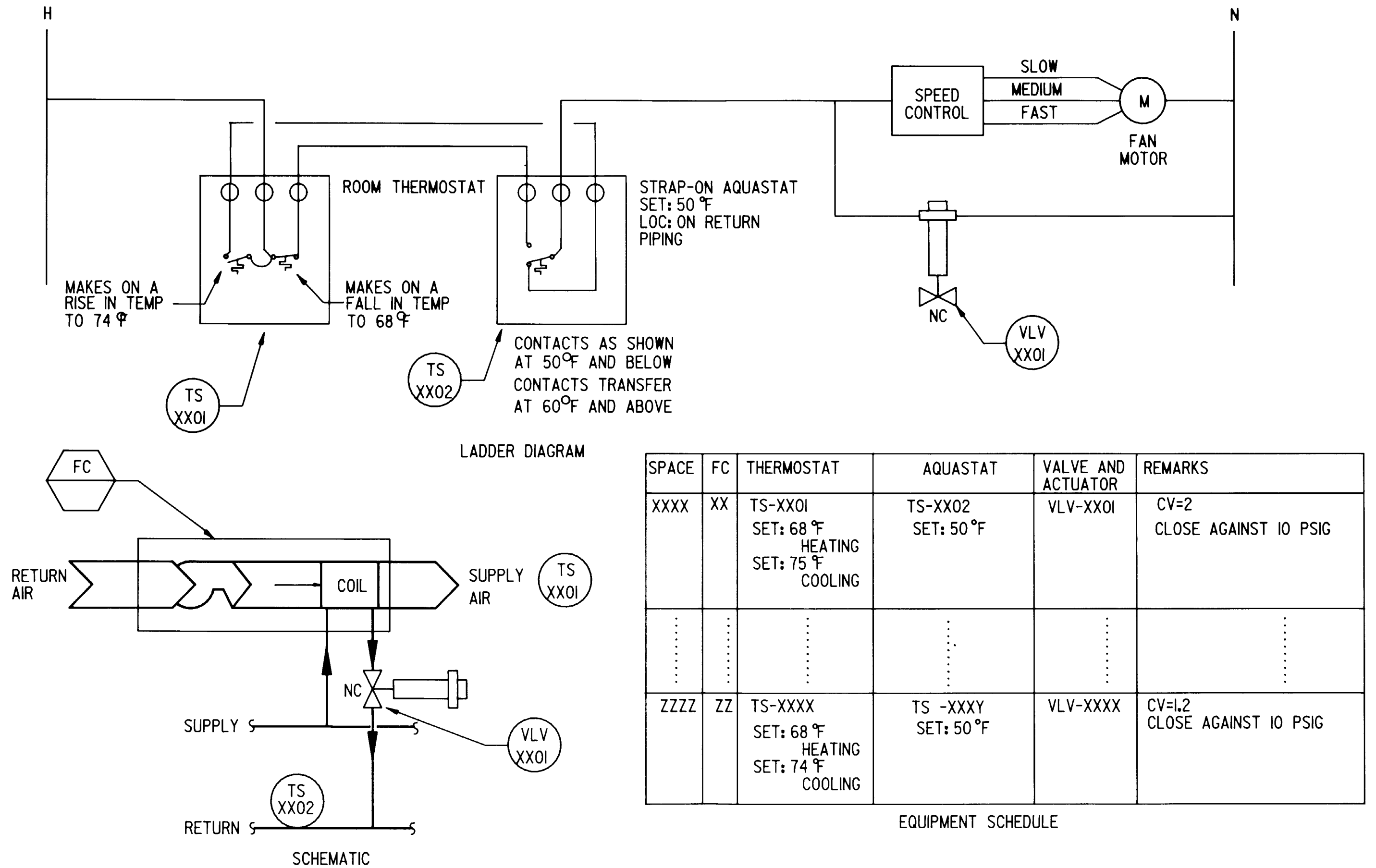


Figure 5-14. Control-system variation for 2-way shutoff valves on fan-coil units.

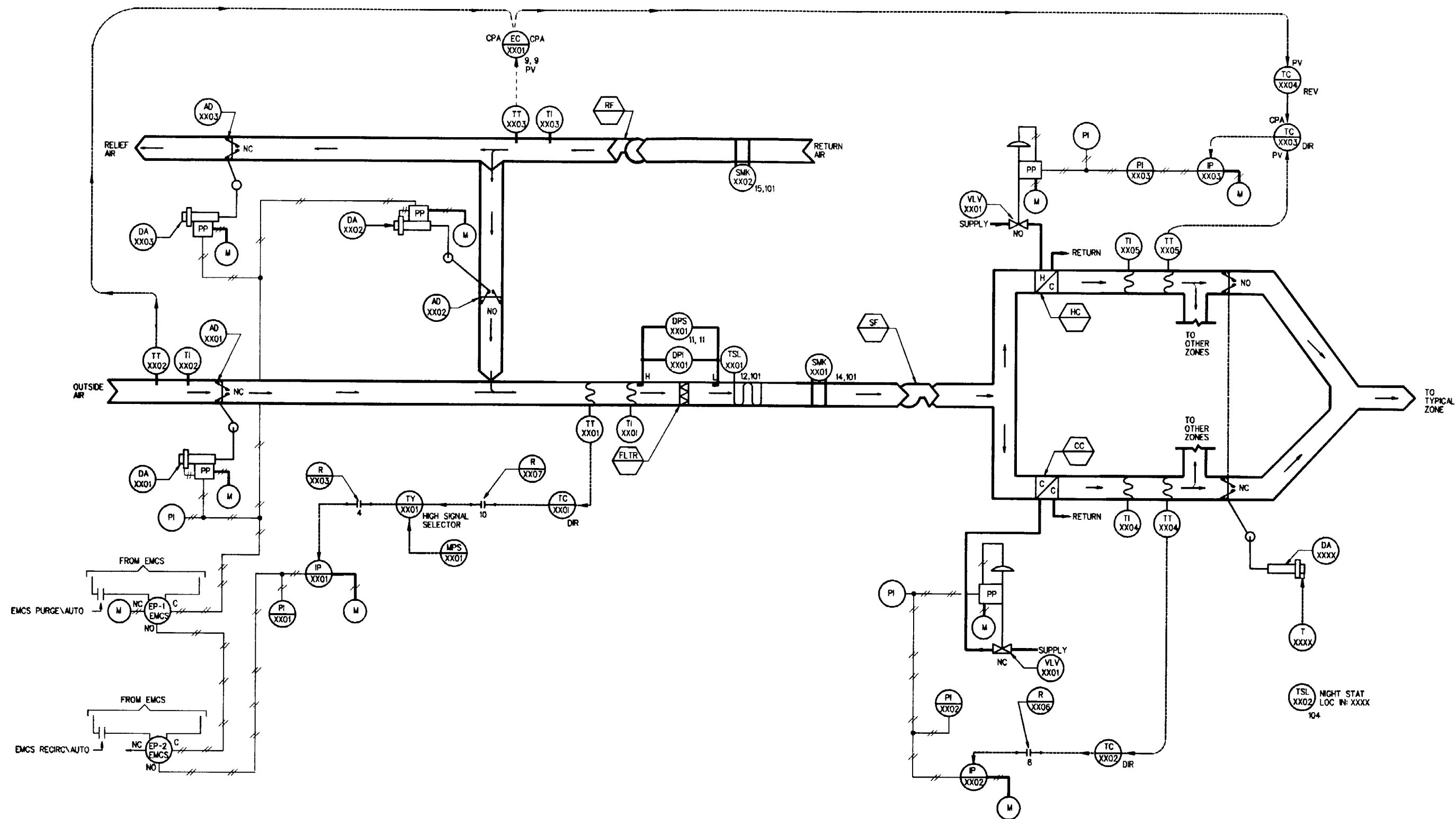


Figure 5-15. Control-system variation for EMCS building-purge and recirculation modes for pneumatic actuators.

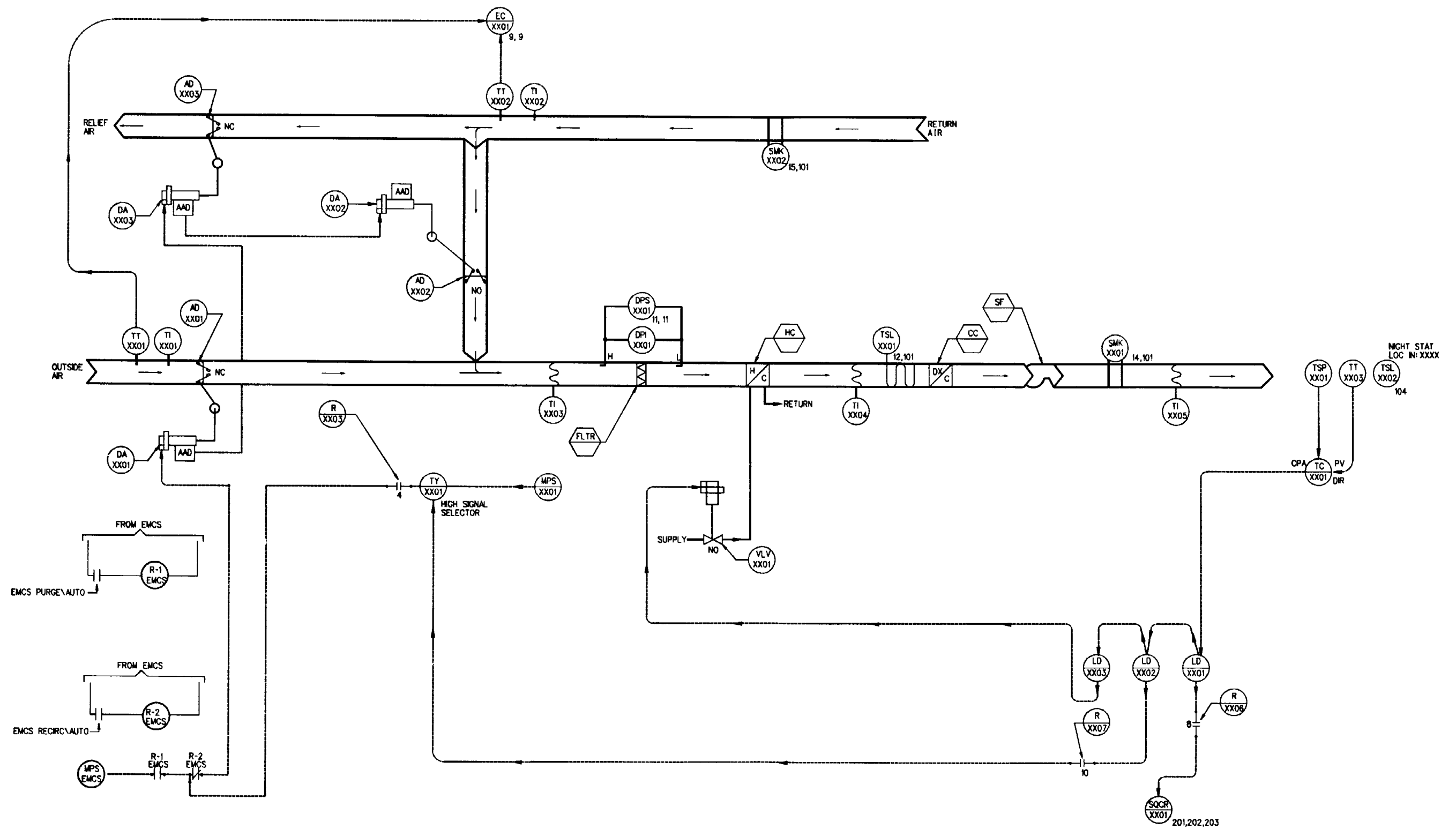


Figure 5-16. Control-system variation for EMCS building-purge and recirculation modes for electric or electronic actuators.

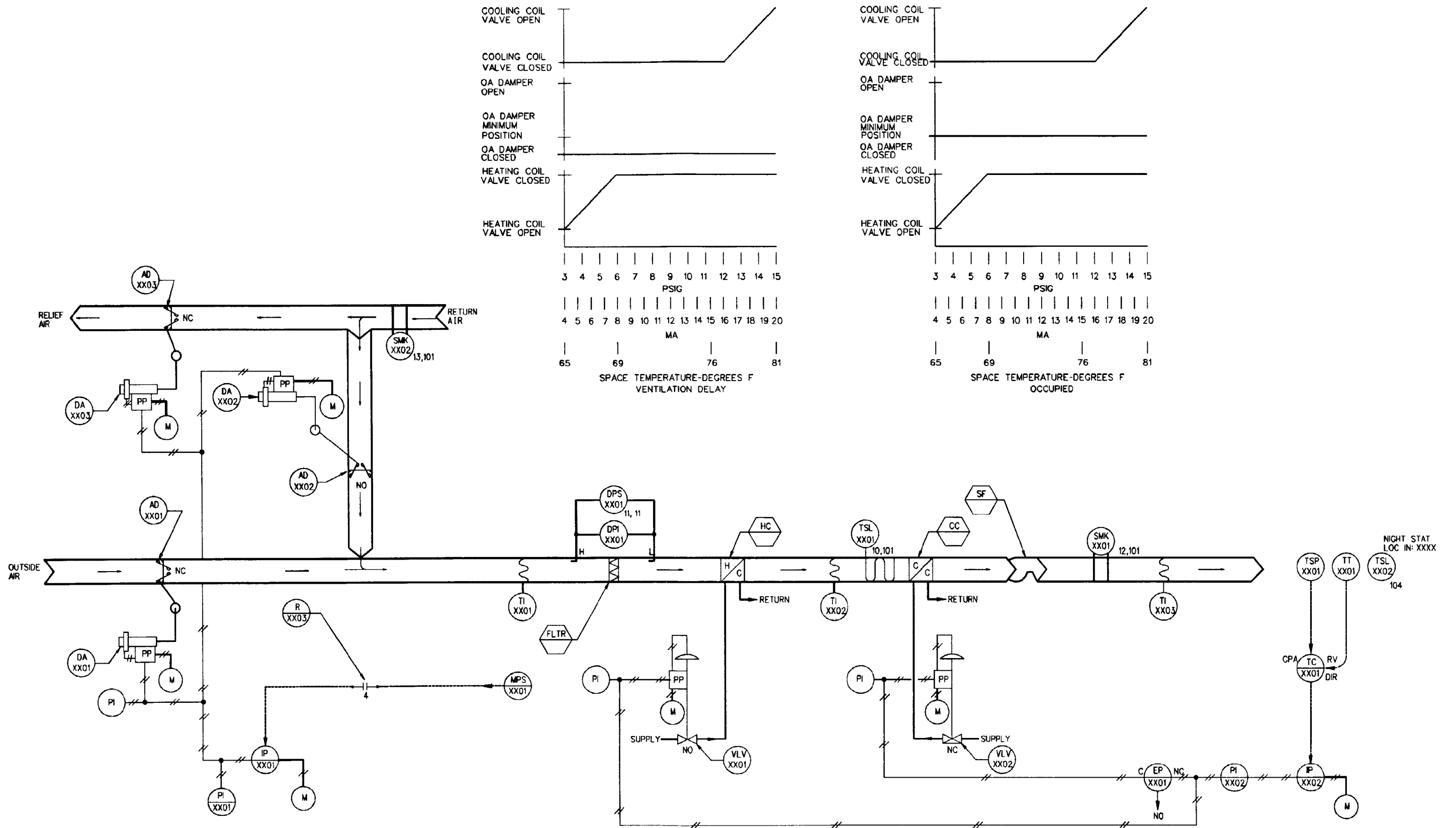
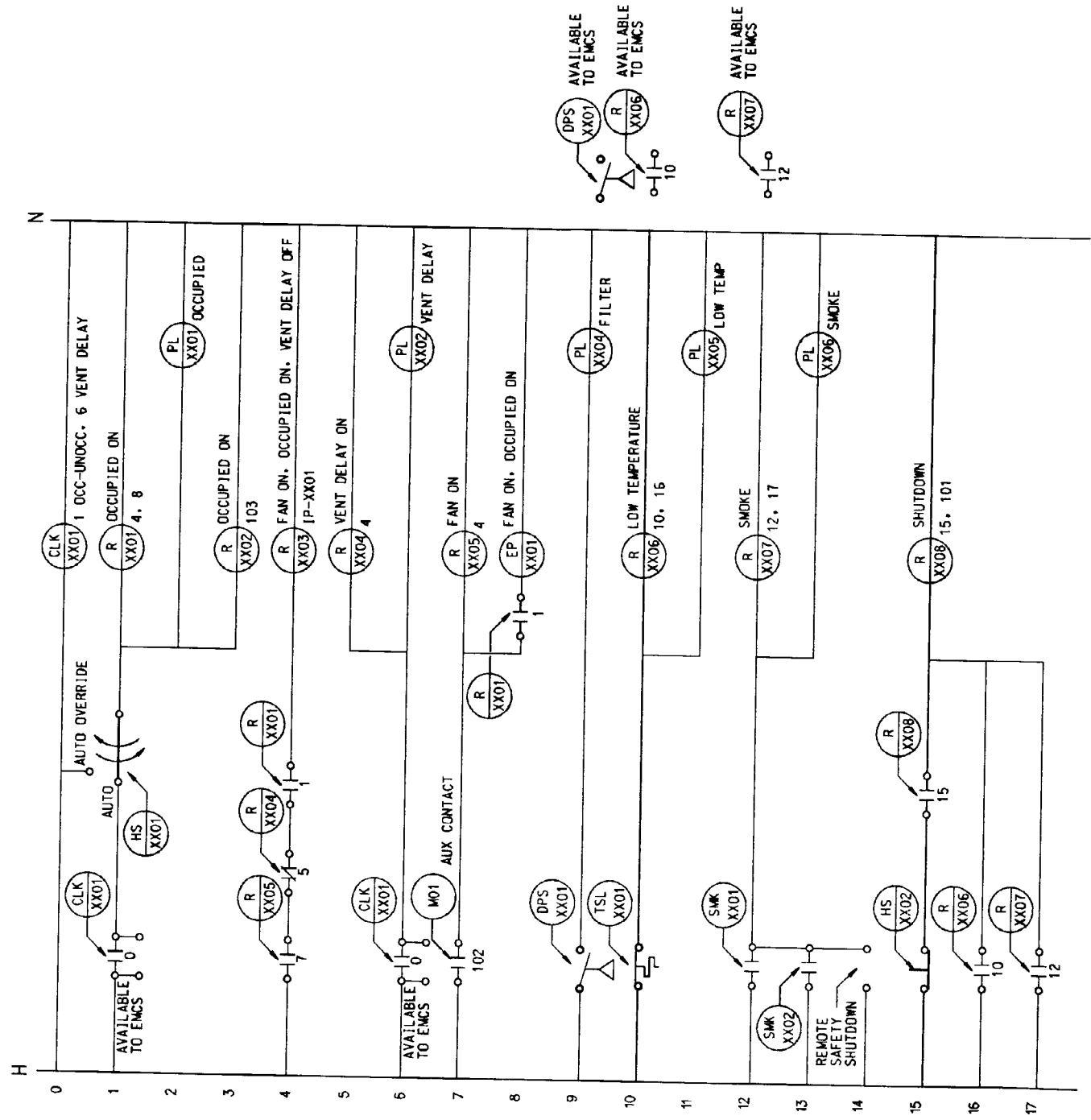
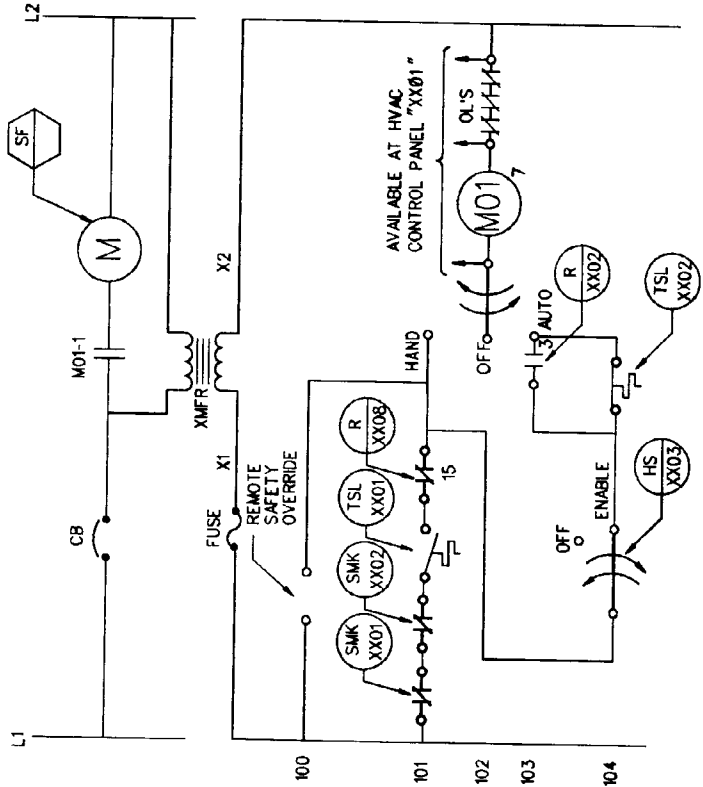


Figure 5-17A. Control-system schematic for single-zone HVAC system without economizer control mode.



HVAC CONTROL PANEL



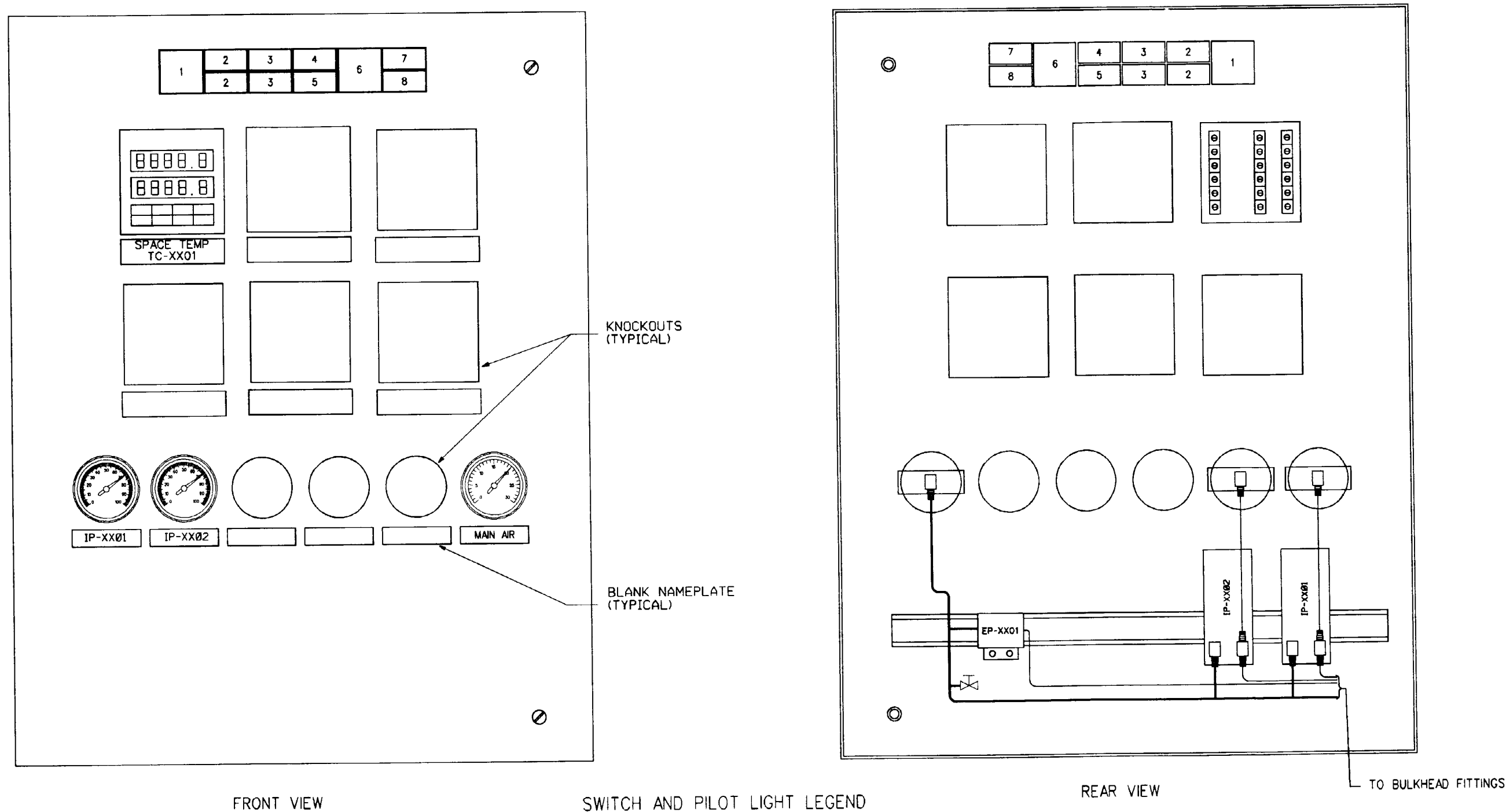
SUPPLY-FAN STARTER

Figure 5-17B. Ladder diagram for single-zone HVAC system without economizer control mode.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
MIXED-AIR TEMPERATURE	DA-XX01, 02, 03	DAMPER ACTUATOR	—	10-15 PSIG	—
	MPS-XX01	MINIMUM-POSITION SWITCH	—	—	SET MIN OA CFM EQUALS 3000 CFM
	TSL-XX01	LOW-TEMPERATURE-PROTECTION THERMOSTAT	35°F	—	—
SPACE LOW TEMPERATURE	TSL-XX02	NIGHT STAT	55°F	5°F DIFFERENTIAL	CLOSE AT 55°F OPEN AT 60°F
SPACE TEMPERATURE	VLV-XX01	HEATING-COIL VALVE	—	3-6 PSIG	CV=12 CLOSE AGAINST 15 PSIG
	VLV-XX02	COOLING-COIL VALVE	—	11-15 PSIG	CV=20 CLOSE AGAINST 20 PSIG
	TC-XX01	SPACE-TEMPERATURE CONTROLLER	SET POINT=73°F PROP BAND=45.7°F MANUAL RESET=50%	50 TO 85°F	SET MAXIMUM LIMITS AVAILABLE TO OCCUPANT BY TSP-XX01 AT 66 TO 72°F
	TT-XX01	SPACE-TEMPERATURE TRANSMITTER	—	50 TO 85°F	—
	TSP-XX01	TEMPERATURE-SETPOINT DEVICE	4 MA = 50°F 20 MA = 85°F	—	—
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0705 HRS. OPEN: 1700 HRS M.T.W.TH.F	OPEN: SAT. SUN AND HOLIDAYS
VENTILATION-DELAY MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS. OPEN: 0800 HRS M.T.W.TH.F	

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS, AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 5-17C. Equipment schedule for single-zone HVAC system without economizer control mode.



POSITION LEGEND

- 1 - RESET
- 2 - AUTO/AUTO OVERRIDE
- 3 - ENABLE/OFF
- 4 - LOW TEMP
- 5 - SMOKE

DEVICE TYPE

- NON-ILLUMINATED MOMENTARY
PUSHBUTTON SWITCH
- ILLUMINATED MAINTAINED CONTACT
INTERLOCKED SWITCHES
- ILLUMINATED MAINTAINED CONTACT
INTERLOCKED SWITCHES
- PILOT LIGHT
- PILOT LIGHT

IDENTIFIER

- HS-XX02
- HS-XX01
- HS-XX03
- PL-XX05
- PL-XX06

POSITION LEGEND

- 6 - FILTER
- 7 - OCC
- 8 - VENT DELAY

DEVICE TYPE

- PILOT LIGHT
- PILOT LIGHT
- PILOT LIGHT

IDENTIFIER

- PL-XX04
- PL-XX01
- PL-XX02

Figure 5-17D. Control-panel interior-door layout for single-zone HVAC system without economizer control mode.

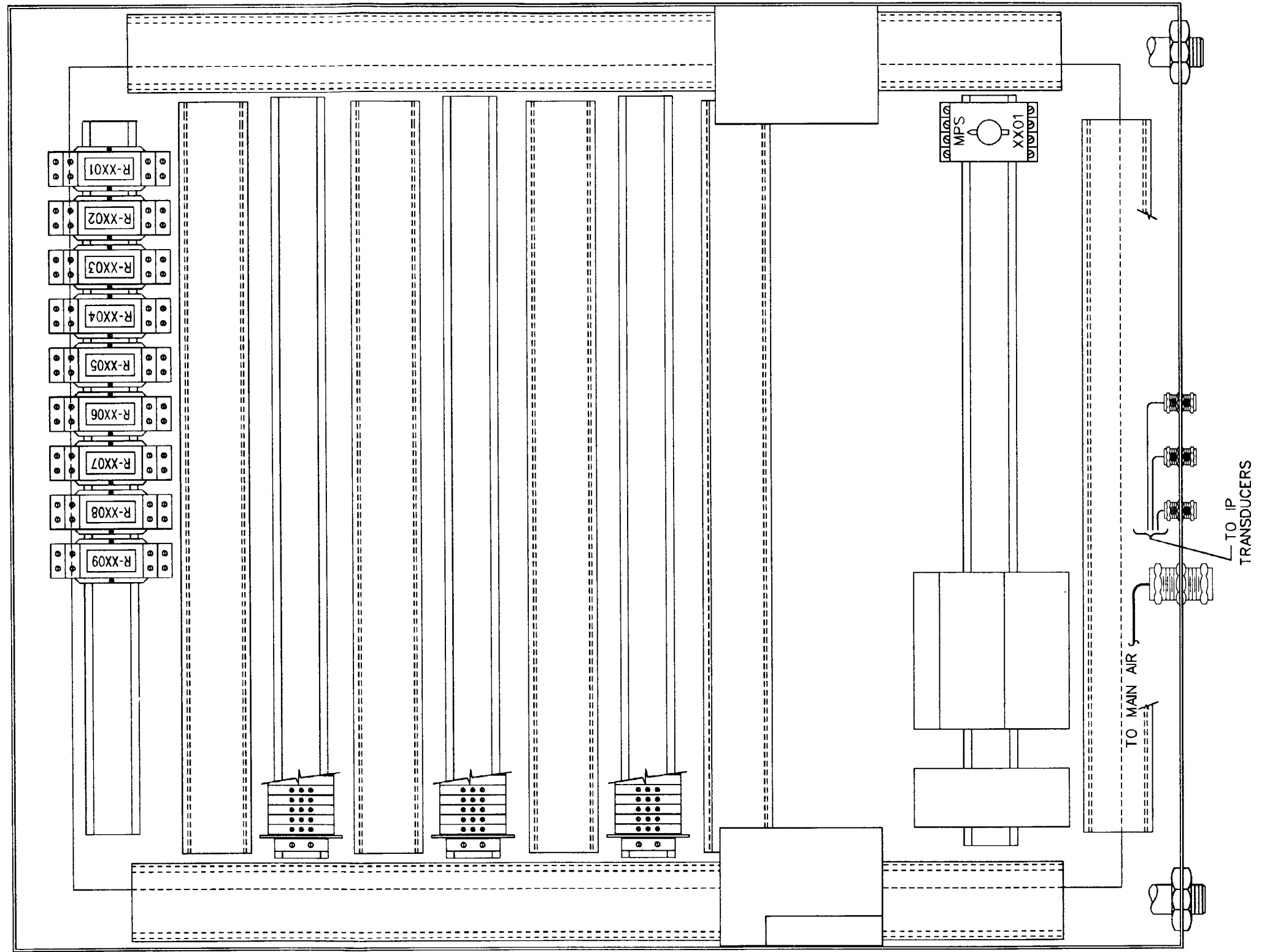


Figure 5-17E. Control-panel back-panel layout for single-zone HVAC system without economizer control mode.

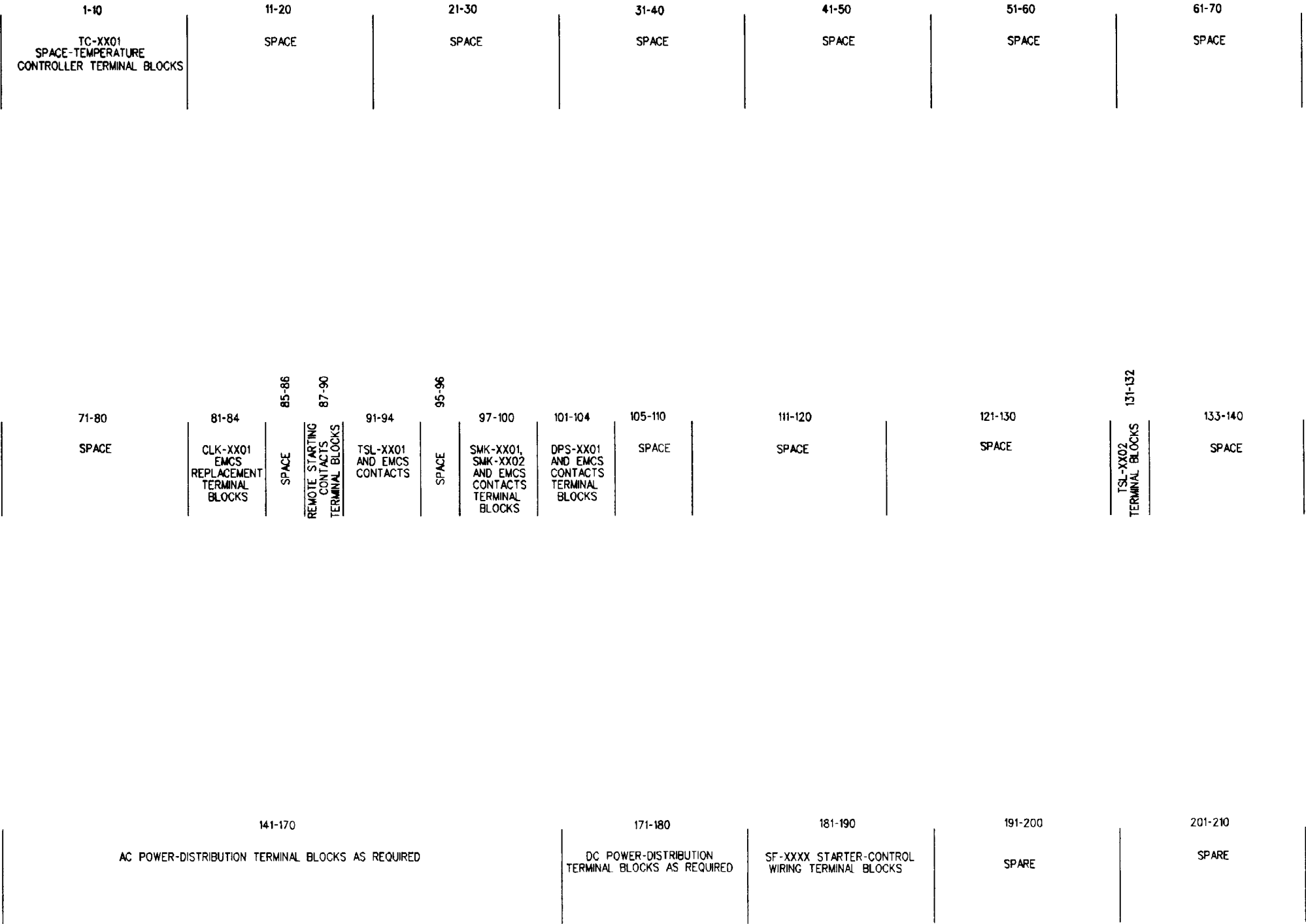


Figure 5-17F. Control-panel terminal-block layout for single-zone HVAC control system without economizer control mode.

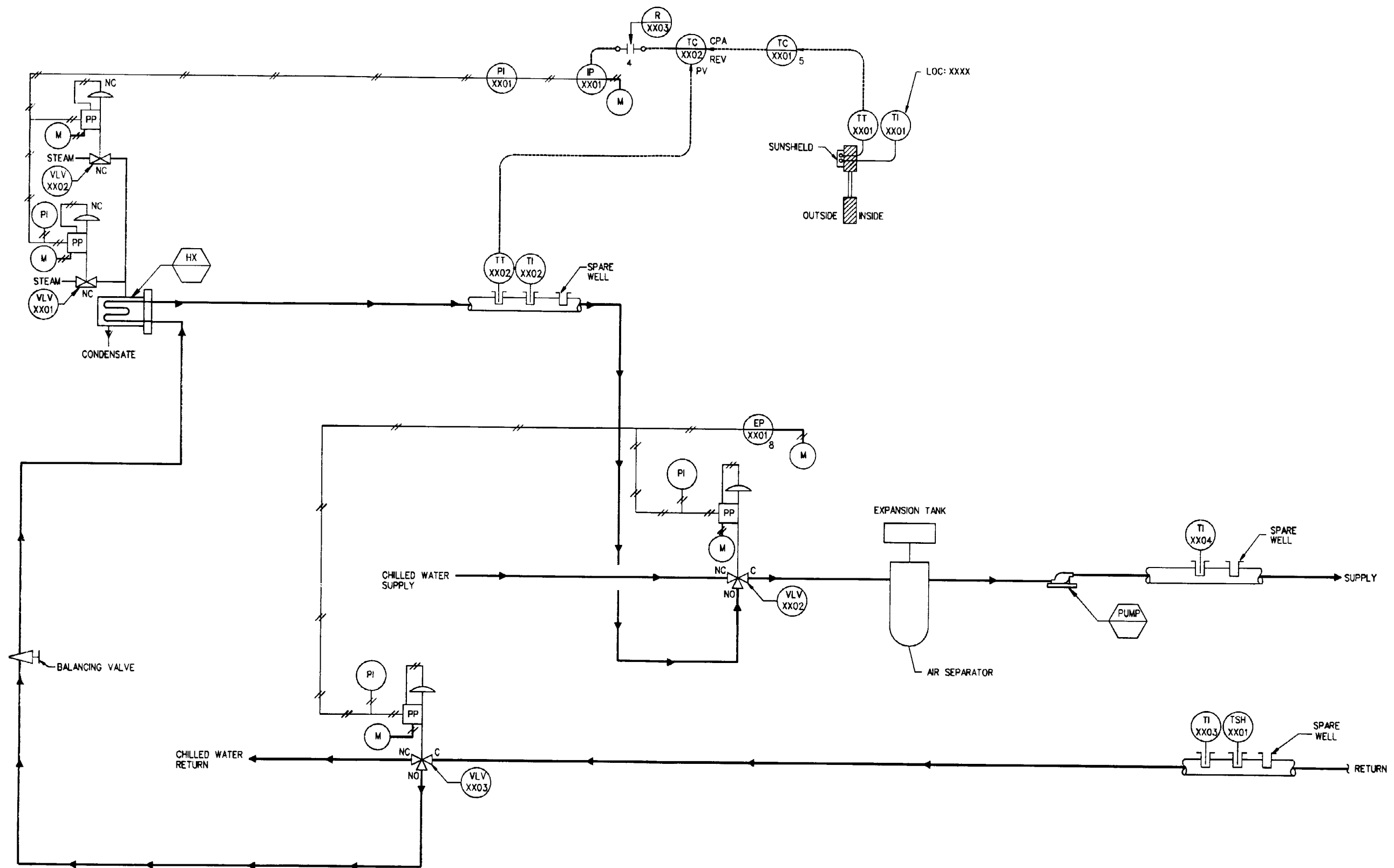


Figure 5-18. Schematic variations for dual steam valves.

LOOP CONTROL FUNCTION	DEVICE NUMBER	DEVICE FUNCTION	SETPOINT	RANGE	ADDITIONAL PARAMETERS
DUAL-TEMPERATURE SUPPLY TEMPERATURE	VLV-XX01	CONVERTOR VALVE	3-8	—	CV-12 CLOSE AGAINST 10 PSIG
	VLV-XX02	CONVERTOR VALVE	8-15	—	CV-26 CLOSE AGAINST 10 PSIG
	TC-XX01	OUTSIDE-AIR TEMPERATURE CONTROLLER	—	-30° TO +130 °F	PV-1 CONTACT STARTS PUMP AT 60 °F STOPS PUMP AT 62 °F
	TC-XX02	SYSTEM-SUPPLY TEMPERATURE CONTROLLER	OA TEMP-0 °F, SUPPLY TEMP-200 °F OA TEMP-60 °F, SUPPLY TEMP-80 °F	100 TO 250 °F	
	TT-XX01	OUTSIDE-AIR TEMPERATURE TRANSMITTER	—	-30° TO +130 °F	—
	TT-XX02	SYSTEM-SUPPLY TEMPERATURE TRANSMITTER	—	100 TO 250 °F	—
DUAL-TEMPERATURE CHANGEOVER	VLV-XX02	SUPPLY-CHANGEOVER VALVE	3-15 PSIG	—	CV-19 CLOSE AGAINST 30 PSIG
	VLV-XX03	RETURN-CHANGEOVER VALVE	3-15 PSIG	—	CV-19 CLOSE AGAINST 30 PSIG
	TSL-XX01	SYSTEM-RETURN CHANGEOVER	THERMOSTAT	30 TO 240 °F	PV CONTACT CLOSE AT 85 °F OPEN AT 90 °F
OCCUPIED MODE	CLK-XX01 CONTACT	365-DAY SCHEDULE	—	NORMAL SCHEDULE CLOSED: 0700 HRS. OPEN: 1700 HRS M.T.W.TH.F	OPEN: SAT, SUN AND HOLIDAYS

NOTE: OTHER CONTROL DEVICES SUCH AS IPS, RELAYS AND SIGNAL SELECTORS ARE NOT SHOWN

Figure 5-19. Equipment-schedule variations for dual steam valves.

Chapter 6

Retrofit of Existing HVAC Control Systems

6-1. Introduction

When determining whether to retain or replace existing control systems (in whole or in part) in the retrofit of existing HVAC systems, the designer must evaluate the applicability of the design guidance provided in this manual. The reason for this evaluation is that deviation from this guidance may be necessary in certain circumstances to prevent adverse impacts on the operation and performance of the retrofitted HVAC systems. Examples of control-system situations that require such evaluation are as follows:

- a. Reuse of existing valves, where their sizes may affect the existing or new hydronic systems and their pump sizing.
- b. Reuse of existing dampers, where their sizes may affect the existing or new air-handling systems and their fan sizing.
- c. Replacing three-way valves with two-way valves and vice versa and its effect on hydronic systems and their pump sizing.
- d. Partial retrofit, where only the final elements such as dampers, valves, and operators may be left in place.
- e. Retrofits involving economizer control loops.
- f. HVAC systems that may not match the systems shown in chapter 4 or their variations in chapter 5.

6-2. Valve sizing and its effect on hydronic systems

Quite likely the guidance provided in this manual for the sizing of control valves differs from the design criteria on which the existing control valves (in a retrofit project) were selected. Consequently, the designer must compare the pressure drop across the existing control valve with the pressure drop for a control valve based on the sizing requirements of this manual. If the existing valve sizes do not meet the pressure-drop requirement for sizing valves in accordance with this manual, it may be that the sizing of the existing valves was based on pressure drop through the valves lower than required by the manual. The designer must then determine if the existing pumping system can provide adequate flow throughout the system with new valves (sized in accordance with this manual) in place. If not, the existing pumping system will have to be upgraded or replaced if the valve-sizing pressure-drop guidance of this manual is applied.

6-3. Damper sizing and its effect on air-handling system

Evaluation of control dampers in a retrofit project is similar to control-valve evaluation, because changing the size of an existing damper would change the damper’s pressure drop and in turn affect fan air-volume delivery. Also, the damper actuators might have to be retrofitted if the evaluation shows a change in the damper’s pressure drop.

6-4. Replacement of 3-way and 2-way valves

Whenever there is a change in the type of control valve in a retrofit project (either from a 2-way valve to a 3-way valve or vice versa), the designer must make additional pressure and flow evaluations. If the change is from 3-way to 2-way, the pressure could increase significantly with a significant pumping system flow decrease as the valve closes. Conversely, the change from 2-way to 3-way could cause significant pressure decrease and flow increase. In either case, there could be adverse effects on HVAC system performance. The designer must evaluate and account for the new pressure drops in deciding whether to change the type of valve.

6-5. Retrofit projects where only final elements may be left in place

Some HVAC retrofit projects may involve new controls but may not require replacement of existing primary elements such as dampers, valves, sensing elements, or other measurement devices. In such instances, the designer must insure that the control signals (both input and output) and actuators for the final elements are in accordance with the design guidance provided in this manual.

6-6. Retrofits involving economizer control loops

If an HVAC system with an economizer mode of operation is to be retrofitted, or if an economizer mode is to be added to an existing HVAC system, the economizer components must be in accordance with the guidance described in the manual.

6-7. Retrofit projects involving HVAC systems not covered in this manual.

When an individual HVAC control system not shown in this manual requires upgrading, it may not be feasible nor suitable to follow the guidance of this manual. It is most likely that maintaining consistency with the remainder of the control system is of more value. It is the responsibility of the designer to evaluate existing conditions to determine the suitability of following the guidance of this manual.

6-8. General considerations for retrofit projects.

- a. Only electric or electronic terminal-unit controls, if serviceable, may be reused.
- b. No existing pneumatic controls except pneumatic valve actuators and damper actuators, if serviceable, may be reused.
- c. If pneumatic actuators are to be reused and the designer finds that their use is justified on the basis of life-cycle cost, the existing air compressors and related accessories, if serviceable, may be reused.
- d. Electric or electronic HVAC control systems with standard signal levels (i.e., 4—20 ma) if serviceable, may be reused.
- e. If existing HVAC systems are retrofitted with control systems designed in accordance with this TM, extension of EMCS to such HVAC systems will interface with the control as shown in this TM.

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Glossary

Section I

Terms, Abbreviations and Acronyms

=	Equal to
<	Less Than
>	Greater Than
A	Ampere
AAD	Auxiliary Actuator Driver
AC	Alternating Current
Accuracy	The degree of conformity of an indicated value to a recognized accepted standard value.
Actuator	A device, that either electrically, pneumatically, or hydraulically operated, changes the position of a valve or damper.
AD	Control Damper
AFMA	Air-Flow Measurement Station
AHU	Air-Handling Unit
AI	Analog Input
Analog	A signal type representing a system variable (such as temperature, humidity, or pressure) that can be measured continuously over a scale.
AO	Analog Output
AUTO	Automatic
Automatic Temperature Control	A local loop network of pneumatic or electric/electronic devices that are interconnected to control temperature.
AUX	Auxiliary
Auxiliary Actuator Driver	An actuator circuit that can be used to control a separate actuator.
Bias	A single-loop digital controller function which maintains a fixed difference in engineering units between controller setpoint and the remote setpoint signal to the controller in engineering units.
BLR	Boiler
C	Common
Cavitation	A phenomenon that results in valve damage from too great a pressure drop through a valve.
CB	Circuit Breaker
CC	Cooling Coil
CDHR	Condenser, Hydronic Return
CDHS	Condenser, Hydronic Supply
CFM	Cubic Feet Per Minute
CH	Chiller

CLK	Time Clock	DD	Dual Duct	EMCS	Energy Monitoring and Control Systems used in military facilities for supervisory control of HVAC control systems and energy-related monitoring and control functions.	HVAC	Heating, Ventilating, and Air Conditioning HWS Hot Water Supply HX Heat Exchanger (Converter)
Closed Loop System	Control system configuration that allows system feedback.	Deadband	A range of thermostat output signal, between the shutoff of heating and start of cooling, in which no heating or cooling energy is used.	EP	The acronym for a two-position electric-solenoid-operated 3-way air valve. (Electric to pneumatic.).	HZ	Cycles Per Second (Hertz)
COND	Condenser	DEG	Degree	Equipment Schedule	A listing of control devices by loop function, unique identifier, setpoints, ranges, and other parameters.	IH	Infrared Heater
Controlled Device	The instrument that receives the controller’s output signal and regulates the controlled process.	Derivative (D) Mode	Control mode in which the output is proportional to the rate of change of the input.	ES	End Switch	Input Signal	The variable signal, received by an instrument, which provides that instrument with a means of changing its output signal.
Controlled Variable	The temperature, humidity, or pressure value to whose variations the controller responds. Controlled variable is also called process variable.	Deviation Contact (DEV)	A single-loop digital controller output contact that can be configured to respond to a given difference between the setpoint of the controller and the process variable input signal.	EXH	Exhaust	INV	Signal-Invertor Module
Controller	The instrument that measures the controlled variable and responds by producing an output signal that holds the controlled variable within preset limits.	DI	Digital Input	F	Fahrenheit, Friday	IO	Input/Output
Controller Feedback	The change in the controller’s output in response to a measured change in the controlled variable that is transmitted back to the controller’s input.	DIA	Diagram	FC	Flow Controller	P	The acronym for a current to pneumatic signal transducer. (I for current and P for pneumatic.)
Control Point	The actual value at which a controller is holding a process variable.	Differential	The difference in values of the controlled variable that will cause a two-position controller to change its output.	FCU	Fan-Coil Unit	Integral (I) Mode	Control mode in which the output is proportional to the time integral of the input; i.e., the rate of change of output is proportional to the input.
Controller Configuration	Information manually entered through a controller keyboard which selects built-in controller options and sets controller parameters.	Differential Pressure	The difference between the static pressures measured at two points in an HVAC system.	FE	Flow-Sensing Element	IV	Inlet Vane
Control-Point Adjustment (CPA)	Adjustment of a controller’s setpoint. The control-point value may vary from the setpoint due to load offset. Control-point adjustment can be accomplished by a signal generated from a local adjustment device, by a signal generated from a remote location, or by means of software.	Digital Single-Loop Controller	A controller that accepts analog input signals, processes the signals digitally according to the controller configuration, and, as a result, produces analog output and two-position output signals.	FLTR	Filter	L1, L2, N	Control-Power Lines and Neutral
Controls	Devices that govern the performance of a system.	Direct Acting	An output signal that changes in the same direction as the controlled or measured variable. An increase in the controlled or measured variable results in an increase in the output signal.	FPM	Feet Per Minute	L	Low
COOL	Cooling	DMPR	Damper	FPS	Feet Per Second	Ladder Diagram	A diagram that shows the electrical control-logic portion of a control system.
CPA	Control-Point Adjustment (Remote-Setpoint Adjustment)	Digital Single-Loop Controller	A controller that accepts analog input signals, processes the signals digitally according to the controller configuration, and, as a result, produces analog output and two-position output signals.	Free-Cooling	Cooling without mechanical refrigeration.	LD	Loop Driver
C.T.	Cooling Tower	Direct Acting	An output signal that changes in the same direction as the controlled or measured variable. An increase in the controlled or measured variable results in an increase in the output signal.	FT	Flow Transmitter	LDR	Ladder
CUH	Cabinet Unit Heater	Differential Pressure	The difference between the static pressures measured at two points in an HVAC system.	FTR	Finned-Tube Radiator	Linearity	A relation such that any change of input signal is accompanied by a similar output change that is directly proportional to the input.
C_v	The liquid flow coefficient of a valve that has the units of gpm per psid and is used to select the valve for a required flow in the open position at a calculated pressure drop.	Digital Single-Loop Controller	A controller that accepts analog input signals, processes the signals digitally according to the controller configuration, and, as a result, produces analog output and two-position output signals.	Function Module	A device for performing a control-loop function between the transmitter and the controller or between the controller output and the controlled devices.	Local-Loop Control	The local pneumatic or electric/electronic controls for any system or subsystem.
D	Derivative Control Mode	DMPR	Damper	Gain	The amount of change in controller output per unit change of controller input.	LOC	Location
DA	Damper Actuator	DO	Digital Output	GC	Glycol Coil	Loop Driver	A device used in control loops to assure that the single-loop digital controller will not be required to drive a loop with a greater impedance than 600 ohms.
DC	Direct Current	DPI	Differential-Pressure Gauge	GPM	Gallons Per Minute	LPS	Low-Pressure Steam
		DPDT	Double-Pole, Double-Throw	H	High	LTHW	Low-Temperature Hot Water
		DPS	Differential-Pressure Switch	HC	Heating Coil	M	Main Air, Motor, Monday
		DPST	Double-Pole, Single-Throw	HD	Head	MA	Milliamp
		DPT	Differential-Pressure Transmitter	Heat	Heating	MAN	Manual
		DX	Direct-Expansion Coil	HFER	Humidifier		
		EA	Each	HL	High Limit		
		EC	Economizer Controller	HOA	Hand-Off-Automatic		
		ECON	Economizer	HP	Horsepower		
		Economizer Mode	The control system mode of operation in which outside air is used for free-cooling of building spaces.	HPS	High-Pressure Steam		
				HR	Heat Recovery		
				HRC	Heat-Recovery Coil		
				HRS	Hours		
				HS	Manual Switch		
		EF	Exhaust Fan	HTHW	High-Temperature Hot Water		

Manual Reset	The act of manually restoring control-circuit electrical continuity after the circuit has been opened by a safety device. A feature of the single-loop digital controller that allows manual adjustment of the analog output signal when proportional mode control is used without integral mode control or derivative mode control.	OUT Output Signal	Output A signal produced in response to an input.	Proportional-integral-Derivative (PID) Mode	integral of the error between setpoint and control point. Control mode in which the output is a value proportional to the input, plus a value proportional to the time integral of the error between setpoint and control point plus a value proportional to the time rate of change of the error.	SAT Schematic	Saturday A diagram that shows the relationship of control devices to control loops and shows the relationship of control loops to systems.
Measured Variable	The uncontrolled variable (such as temperature, relative humidity, or pressure) sensed by the measuring element.	P Parameter	Proportional Control Mode Information and values to be used in configuring a microprocessor controller for its purpose in the control-system application.	PS PSI PSIA	Positive Positioner Pounds Per Square Inch Pounds Per Square Inch, Absolute	SCIM	Standard Cubic Inches Per Minutes
Microprocessor Controller	A microprocessor-based controller (non-analog in processing its internal signals) that performs a dedicated function and does not require software programming.	PE PH PI	Pneumatic-Electric Switch Phase Pressure indicator (Gauge) or Proportional-Plus-Integral Control Mode	PSID PSIG PV R RA Range	Pounds Per Square Inch, Differential Pounds Per Square Inch, Gauge Process Variable Relay Return Air The upper and lower limits of the value of a variable.	Self-Tuning	A single-loop digital controller feature that, when selected, commands the controller to calculate the optimal proportional, integral and derivative mode constants for the process being controlled and to use the calculated constants for control.
MIN Minimum-Position Switch	Minimum A manual switch used to set the position of mixing plenum control dampers to assure that the minimum quantity of outside air is introduced by an HVAC system.	PID PL Positive Positioner	Proportional-Plus-Integral-Plus Derivative Control Mode Pilot Light A mechanical device that measures actuator position and control signal value and sends main air to the actuator to maintain the correct position for the signal.	Ratio	Process Variable Relay Return Air The upper and lower limits of the value of a variable. A single-loop digital controller feature which multiplies the remote setpoint input signal to the controller by a constant and uses the resulting value as the controller setpoint.	Sensitivity	The unit change in controller output per unit change in the controlled variable. Usually expressed in psi or milliamps per degree, cfm, etc.
M01, M02 Modulating Control	Magnetic-Starter Holding coil Control achieved by gradually changing a controller analog output signal to an actuator in response to a change in a sensed variable.	PP Process Control	Positive Positioner The science of regulating variables by measuring, processing, and manipulating process variables coupled to the regulated variables.	Relay	An electric device that changes the position of its contacts when its coil is energized.	Sensing Element Sequence of Operation	A device used to detect or measure physical phenomena. A narrative that describes the actions of control devices such as valves and dampers as the process variable changes in a given direction, such as on a temperature, humidity, or pressure increase.
MPS MZ Normally Closed	Minimum-Position Switch Multizone A controlled device that closes when its power supply or input signal is removed.	Process Variable Process Variable Contact (PV)	See Controlled Variable. A single-loop digital controller output contact that can be configured to respond to a given value of the process variable input signal.	Remote Setpoint Resistance Temperature Detector (RTD)	See Control Point Adjustment. A device whose resistance changes linearly as a function of temperature.	Setpoint	The desired value of the controlled variable at which the controller is set.
Normally Open	A controlled device that opens when its power supply or input signal is removed.	PROP Proportional Band	Proportional A controller parameter setting which determines the change in the number of engineering units of a process variable input signal that will produce a full-scale change of the controller analog output signal.	REV Reverse Acting	Reverse-Acting An output signal that changes in the opposite direction from the controlled or measured variable. An increase in the controlled or measured variable results in a decreased output signal.	SF SHLD Signal Inverter	Supply Fan Sunshield A device that linearly converts a 4 to 20 milliamper input signal to an output signal of 20 to 4 milliamperes.
Normal Mode	The usual or expected operating condition.	Proportional (P) Mode	Control mode in which there is a continuous linear relationship between the input and the output.	RF RH RHC	Return Fan Relative Humidity Relative-Humidity Controller, Reheat Coil	Signal Selector	A device that selects the highest or the lowest of its input signals as its output signal.
OA OCC Offset	Outside Air Occupied The difference between the setpoint of a controller and the actual point of the controlled variable, caused by changes in load.	Proportional-Integral (PI) Mode	Control mode in which the output is proportional to a linear combination of the input plus a value proportional to the time	RHT RHY SA	Relative-Humidity Transmitter Humidity Loop Device Supply Air	SMK Smoke Detector	Smoke Detector A generic term for devices that are used to operate safety circuits on the detection of smoke or products of combustion.
OL Open-Loop System	Overload Control-system configuration that does not have system feedback.					SP S.P. Span	Static Pressure Set point The number of engineering units between the extremes of a calibration range.

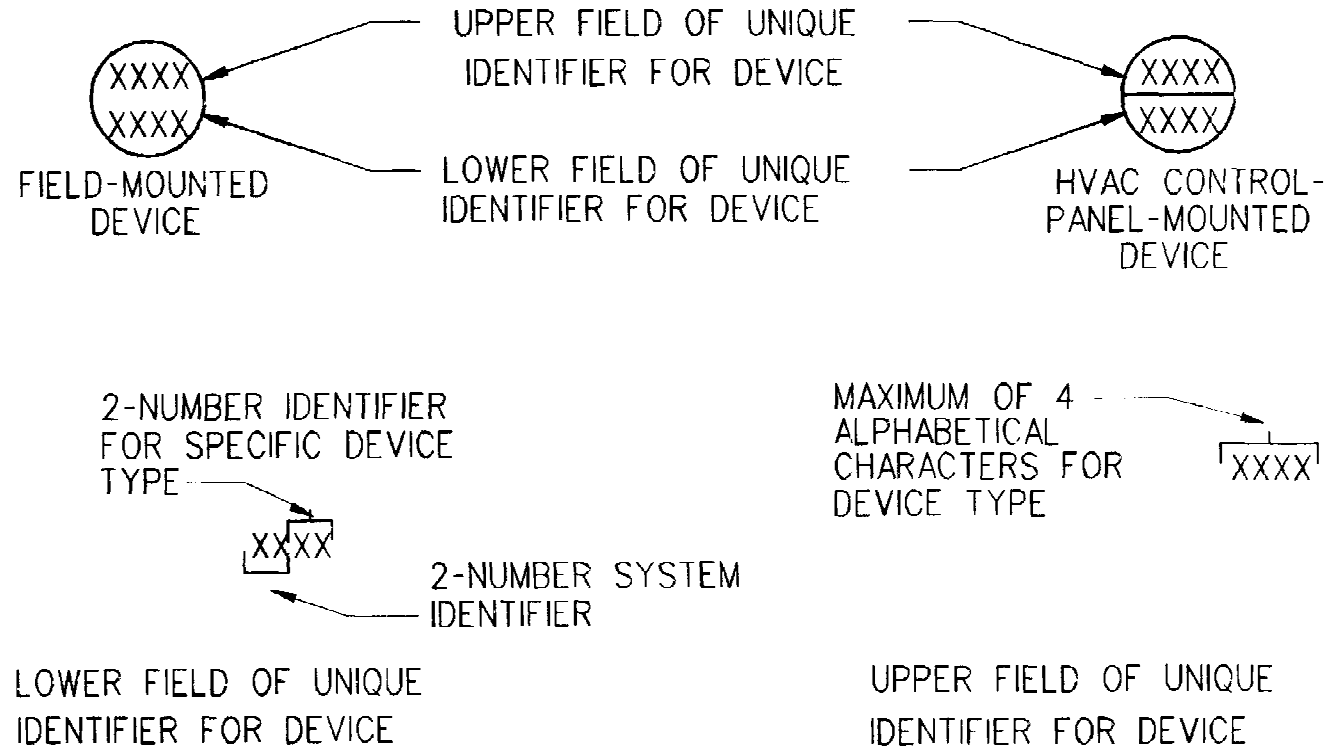
SPRG	Spring Range	System Feedback	System’s response to the controller’s action in changing the value of a controlled variable, as transmitted back to the controller.	TI	Thermometer	Unique identifier	An alphanumeric identifier that consists of: 1) an abbreviation for the type of device; and 2) a number made up of an HVAC-system number and a serial number for the device.
Spring Range	The range over which the input signal to a controlled device must change to move the device from one extreme to the other.			Time Clock	A device that changes the positions of its output contacts according to a timing schedule. Transmitter A transducer that senses the value of a variable and converts this value into a standardized transmission signal.		
SPT	Static-Pressure Transmitter	SZ	Single Zone			UNOCC	Unoccupied
SQCR	Sequencer	T	Modulating Thermostat, Tuesday			VAV	Variable Air Volume
STM	Steam	TC	Temperature Controller	TS	Non-Modulating Space Thermostat or Aquastat	VFDU	Variable-Frequency Drive Unit
SUN	Sunday	TDR	Time Delay Relay	TSL:	Low-Temperature-Protection Thermostat or Nightstat, Non-modulating	VLV	Valve
Sunshield	A device installed outdoors on the surface of a building to house outside-air temperature-sensing elements and to shield them from direct exposure to sun’s radiation.	TE	Temperature-Sensing Element			W	Wednesday
		TEMP	Temperature	TSP	Temperature-Setpoint Device	WTR	Water
Supply Pressure	Gauge pressure of the compressed air supplied to a pneumatic control system, usually 20 psig.	Terminal Unit	A unit through which heating or cooling is distributed to the conditioned space. Terminal units include radiators, unit heaters, gas-fired infrared heaters, variable-air-volume boxes, duct heating coils, and fan-coil units.	Tuning	The process of finding the control-mode constants the use of which results in the stable control of a process at or near the controller setpoint.	X1, X2	transformer Power, Hot and Ground
				TuP	Microprocessor Room Thermost	X	Times (Multiplication)
Supply Voltage	Voltage of the electric energy supply to an electric/electronic control system.	TH	Thursday	TT	Temperature Sensor and Transmitter	XMFR	Transformer
Surge Protection	Methods of protecting signal wiring and power wiring circuits from damage by electrical voltage and current overrange due to such factors as lightning strikes.	Thermostat	A device that senses temperature and changes its output as a result of temperature changes.	Two-Position Control	Control achieved by switching a controller output signal on and off in response to a change in a sensed variable.		
		Throttling Range	The portion of the instrument range of a controlled variable required to move the controlled device from one extreme to the other.	TV	Temperature Loop Device		
				UH	Unit Heater		

SCHEMATICS FOR HVAC CONTROL SYSTEMS WILL USE THE FOLLOWING SYMBOLS TO SHOW AIR FLOW AND ITS DIRECTION.

Section II
Standard Symbols

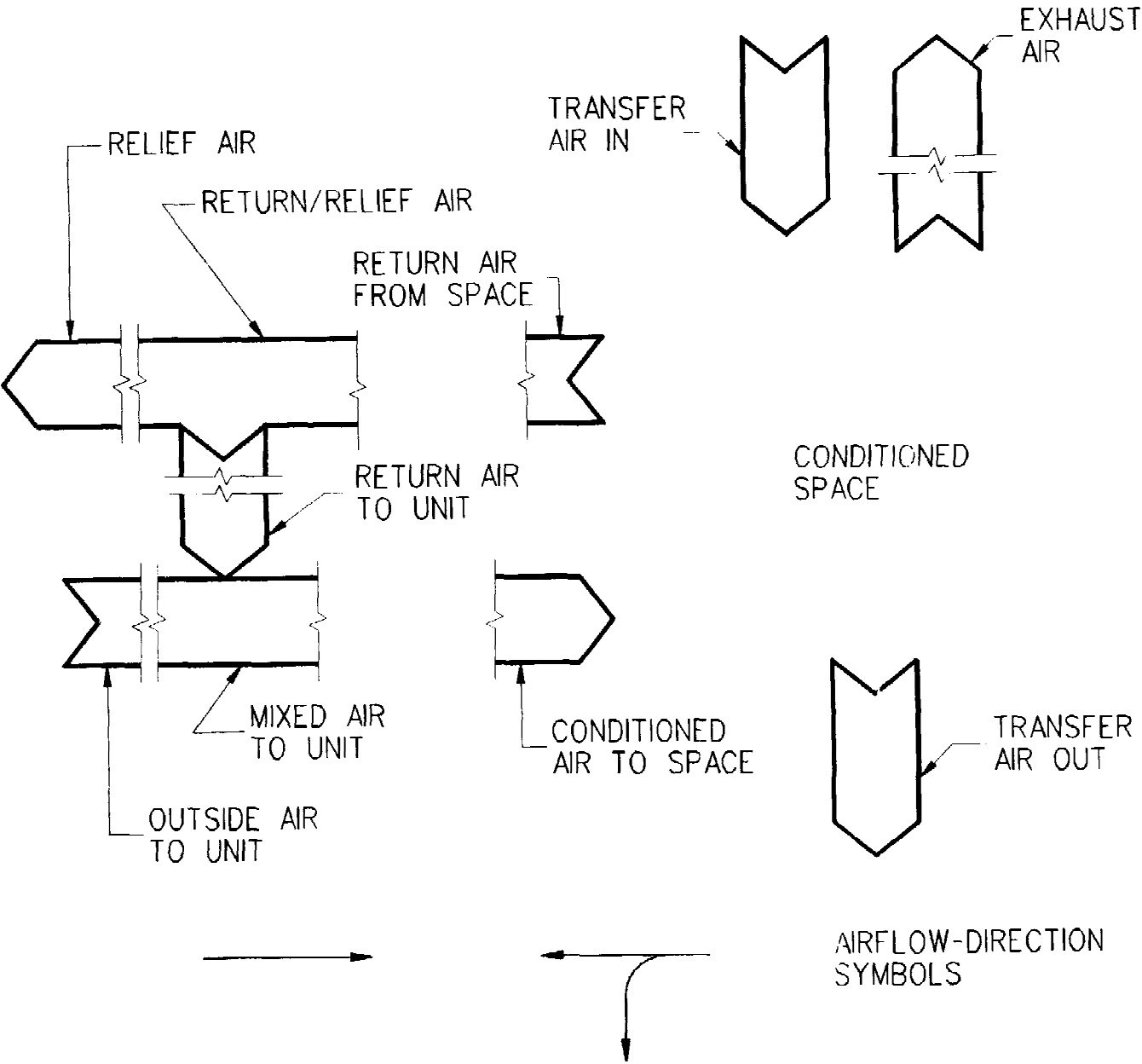
THIS SECTION CONTAINS THE SYMBOLS THAT WILL BE USED FOR HVAC CONTROL-SYSTEM DRAWINGS PRODUCED IN ACCORDANCE WITH THIS TECHNICAL MANUAL.

EACH SYMBOL WILL BE REFERENCED TO A UNIQUE IDENTIFIER, WHICH WILL USE THE FOLLOWING FORMAT:

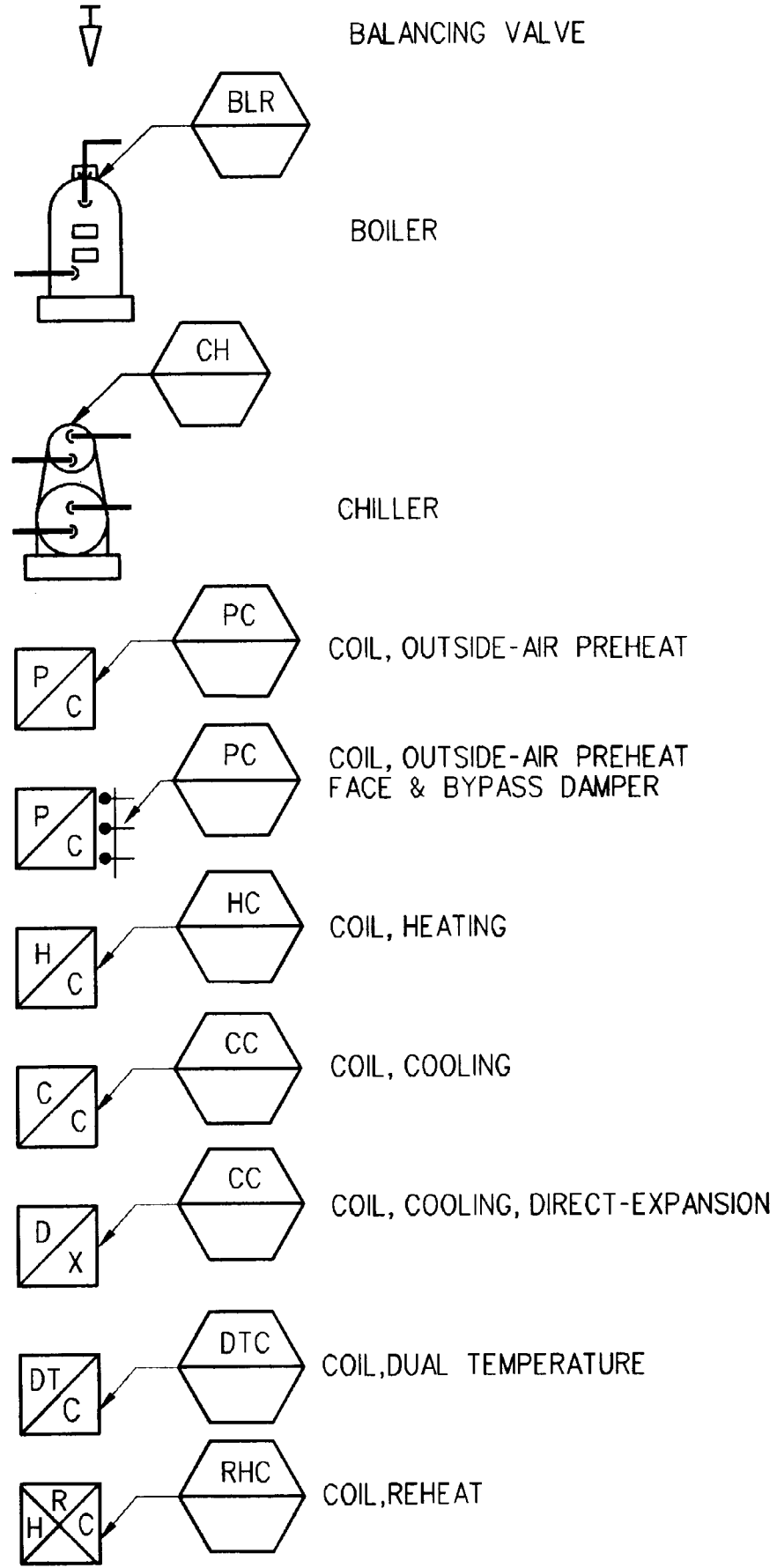
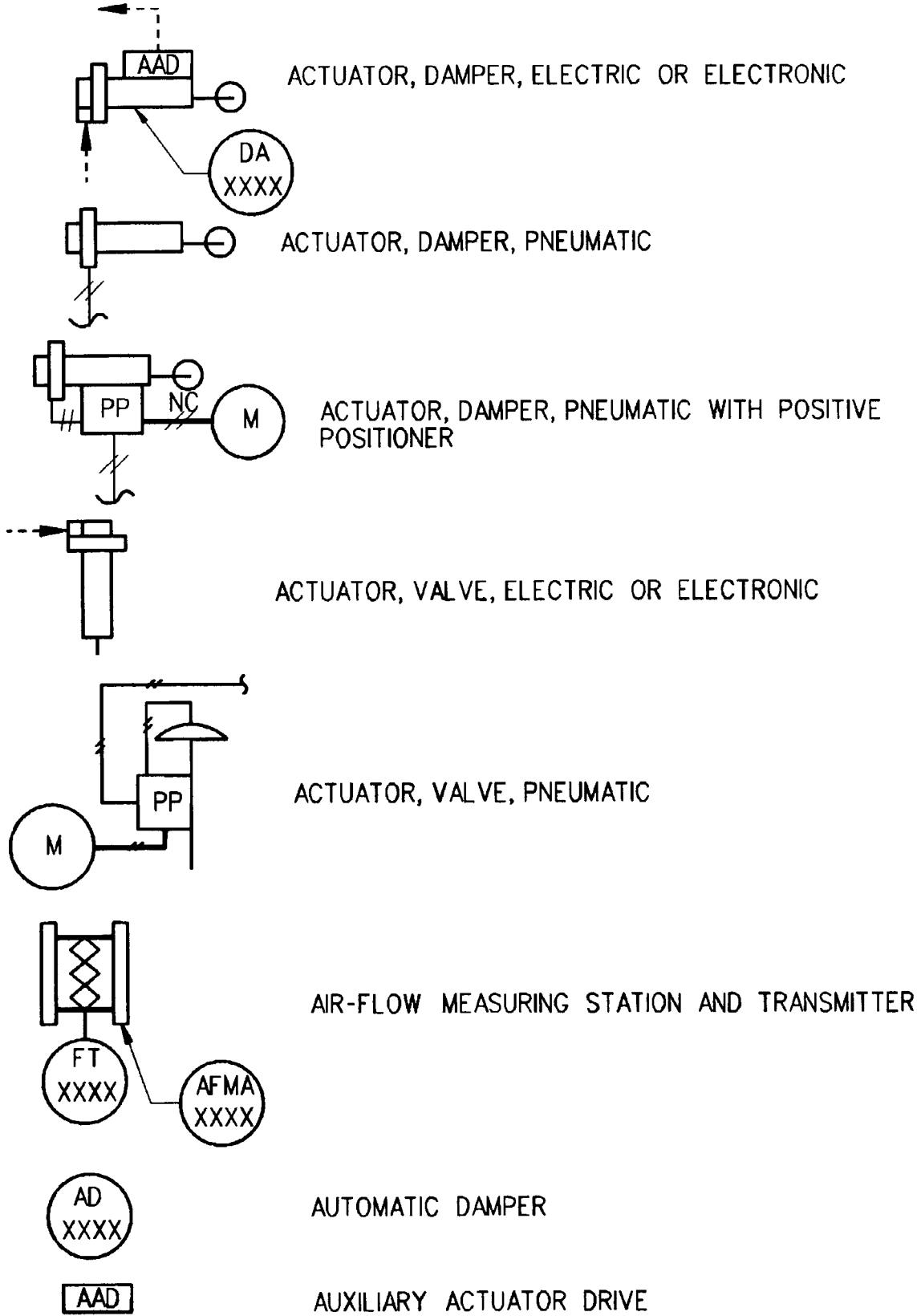


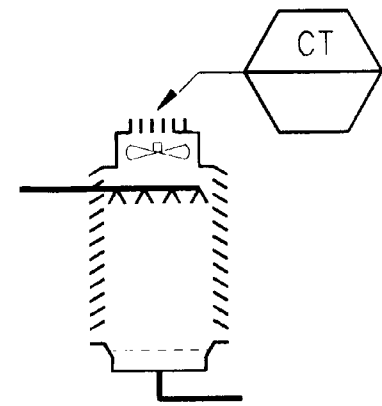




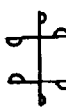





TYPICAL DUCT SYMBOL SHOWING AIR FLOW DIRECTION.

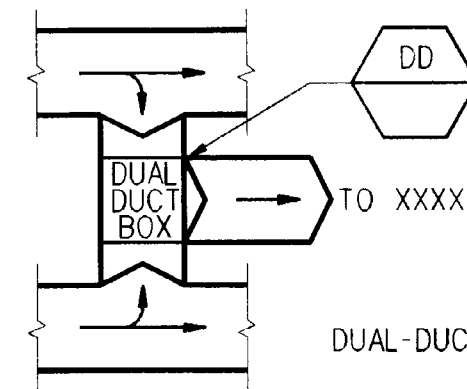
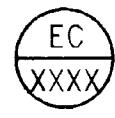


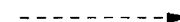

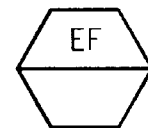

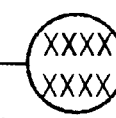

STANDARD REPRESENTATION
OF AIR FLOW TO AND FROM
CONDITIONED SPACE

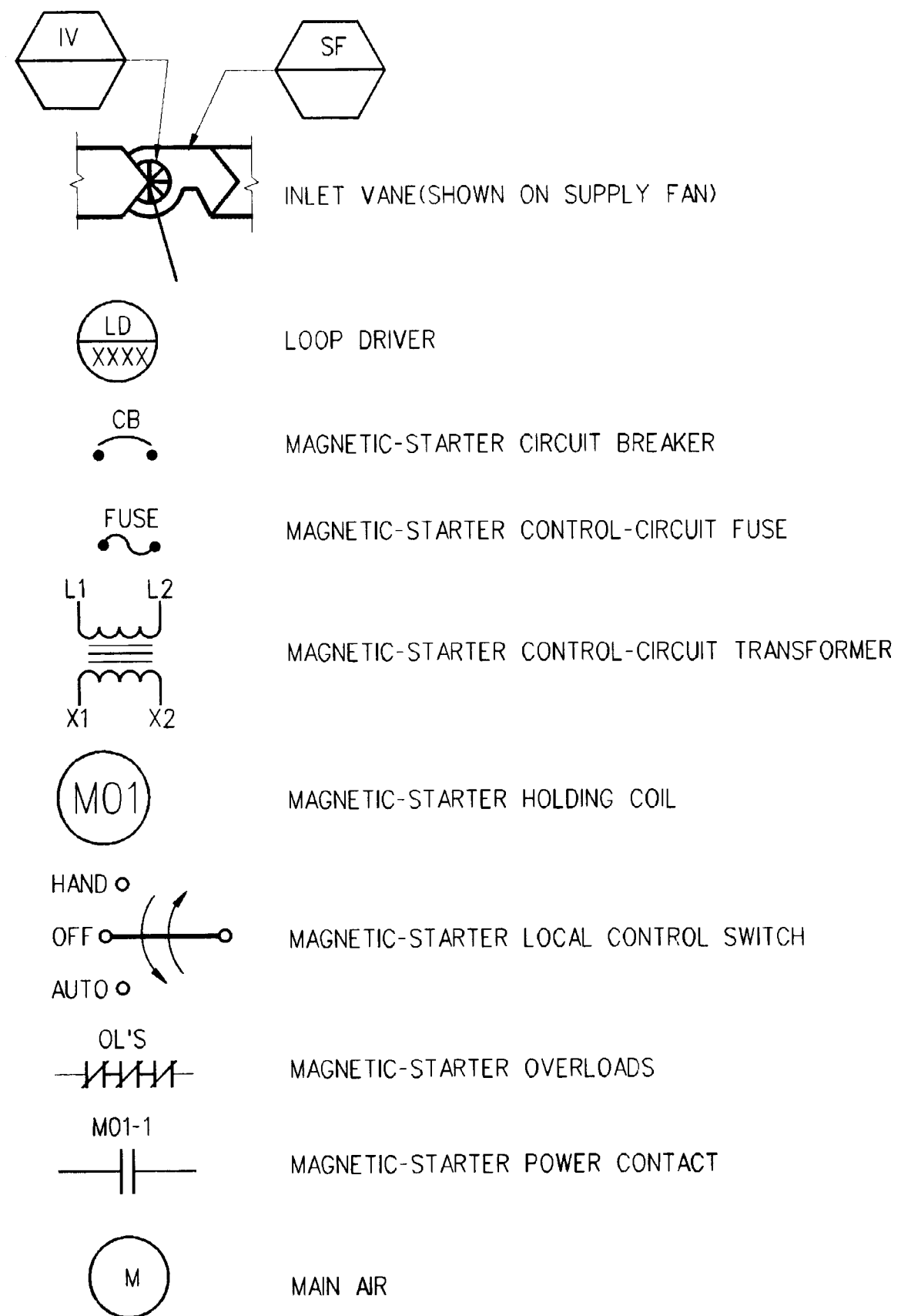
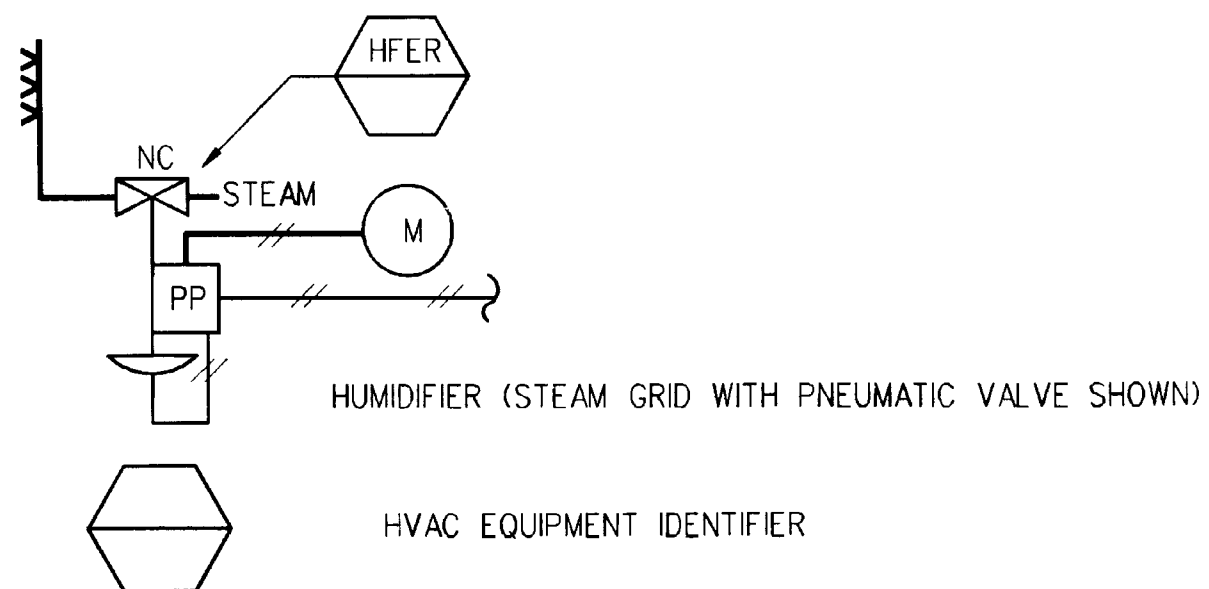
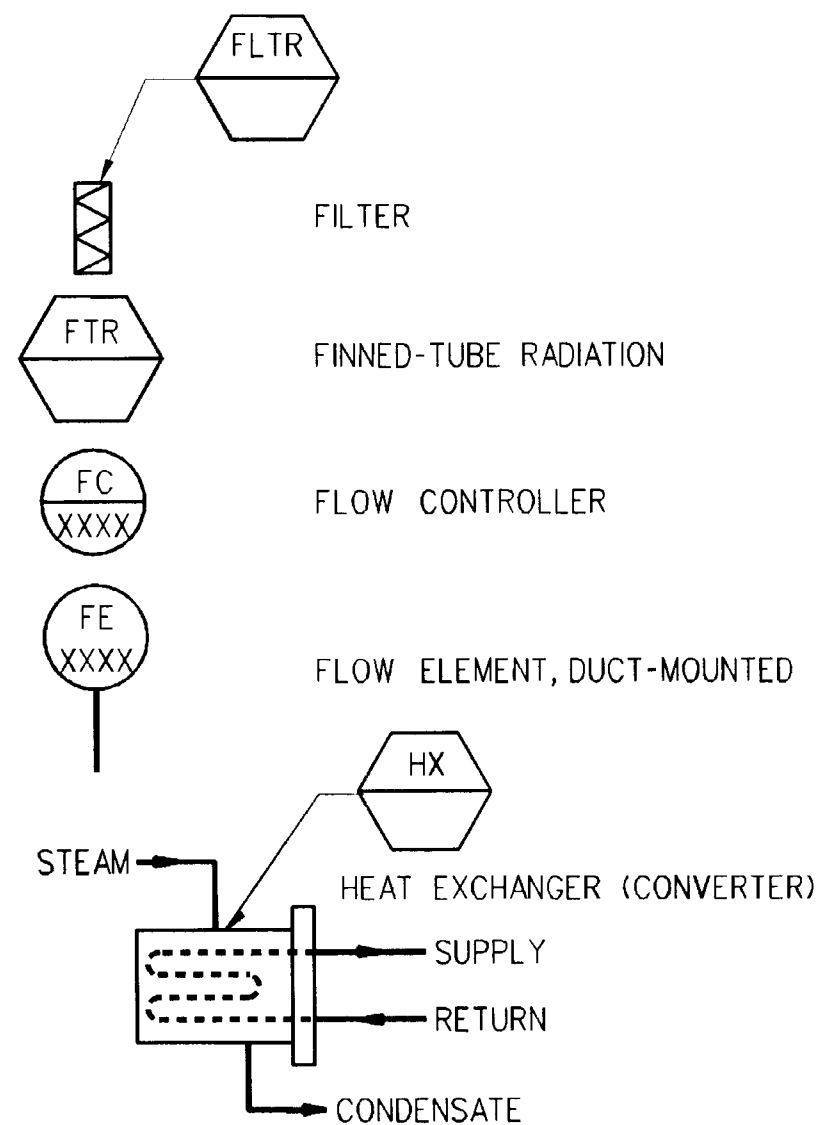


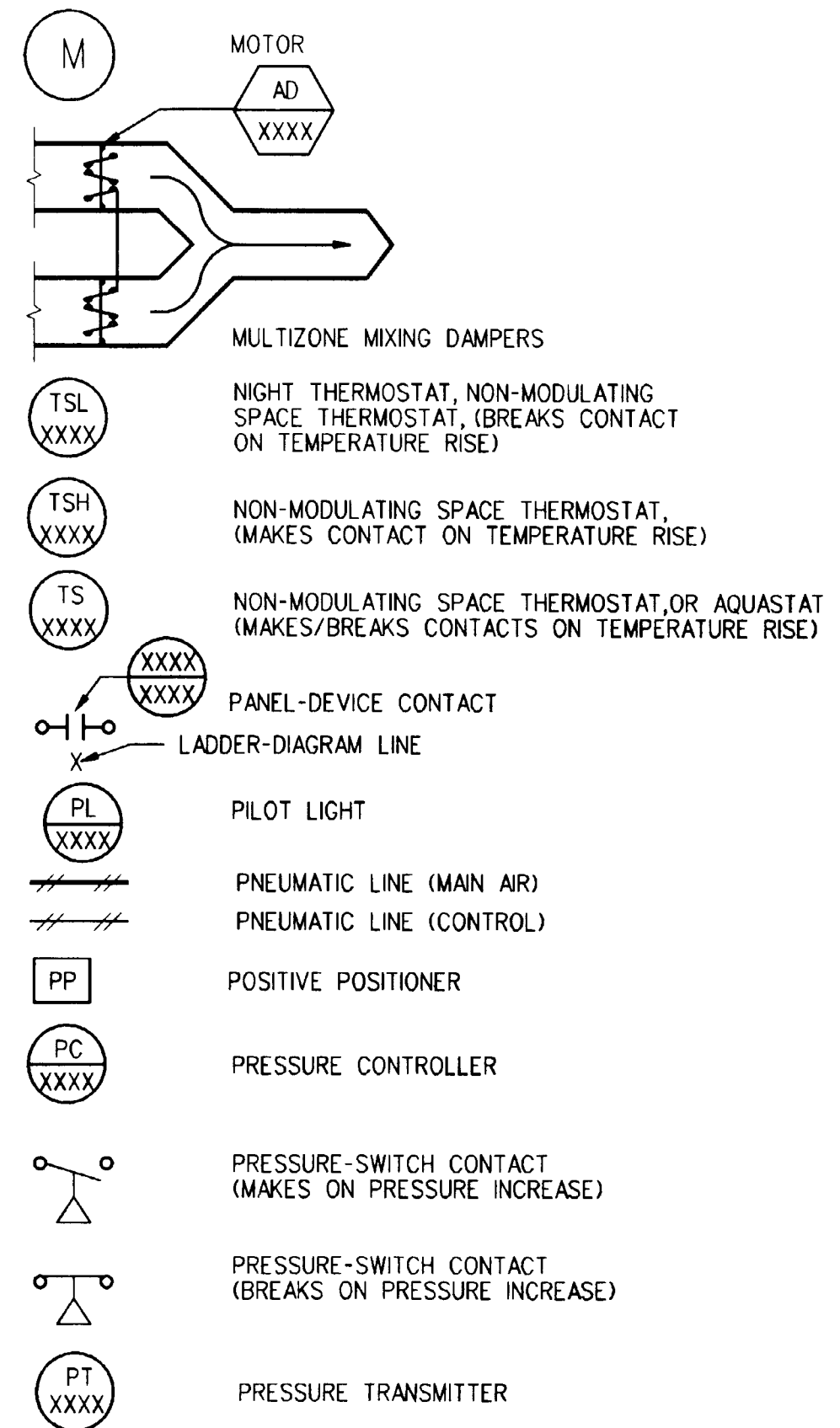
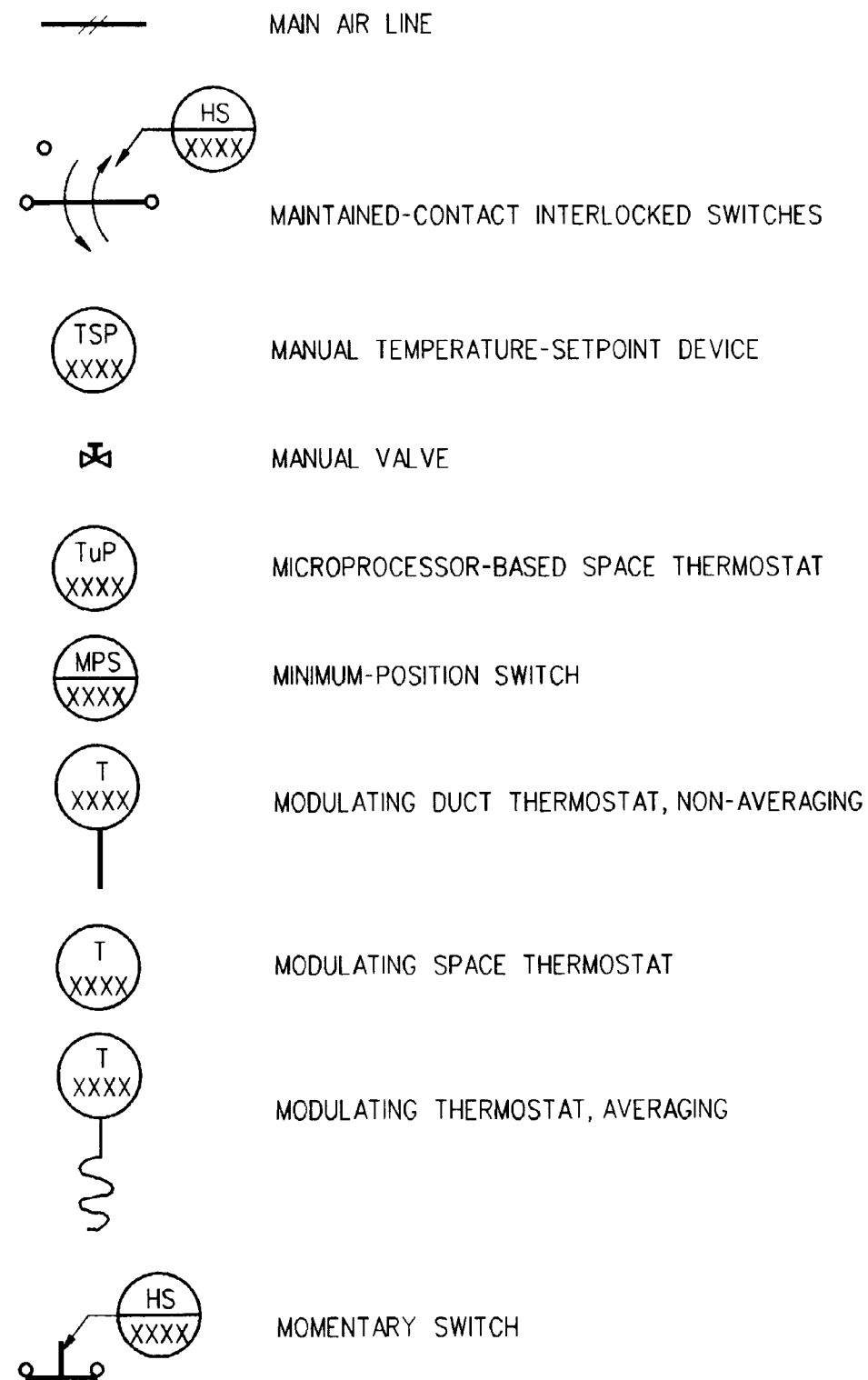
INSTRUMENTATION AND CONTROL-DEVICE SYMBOLS FOR HVAC
CONTROL-SYSTEM DRAWINGS ARE AS FOLLOWS:

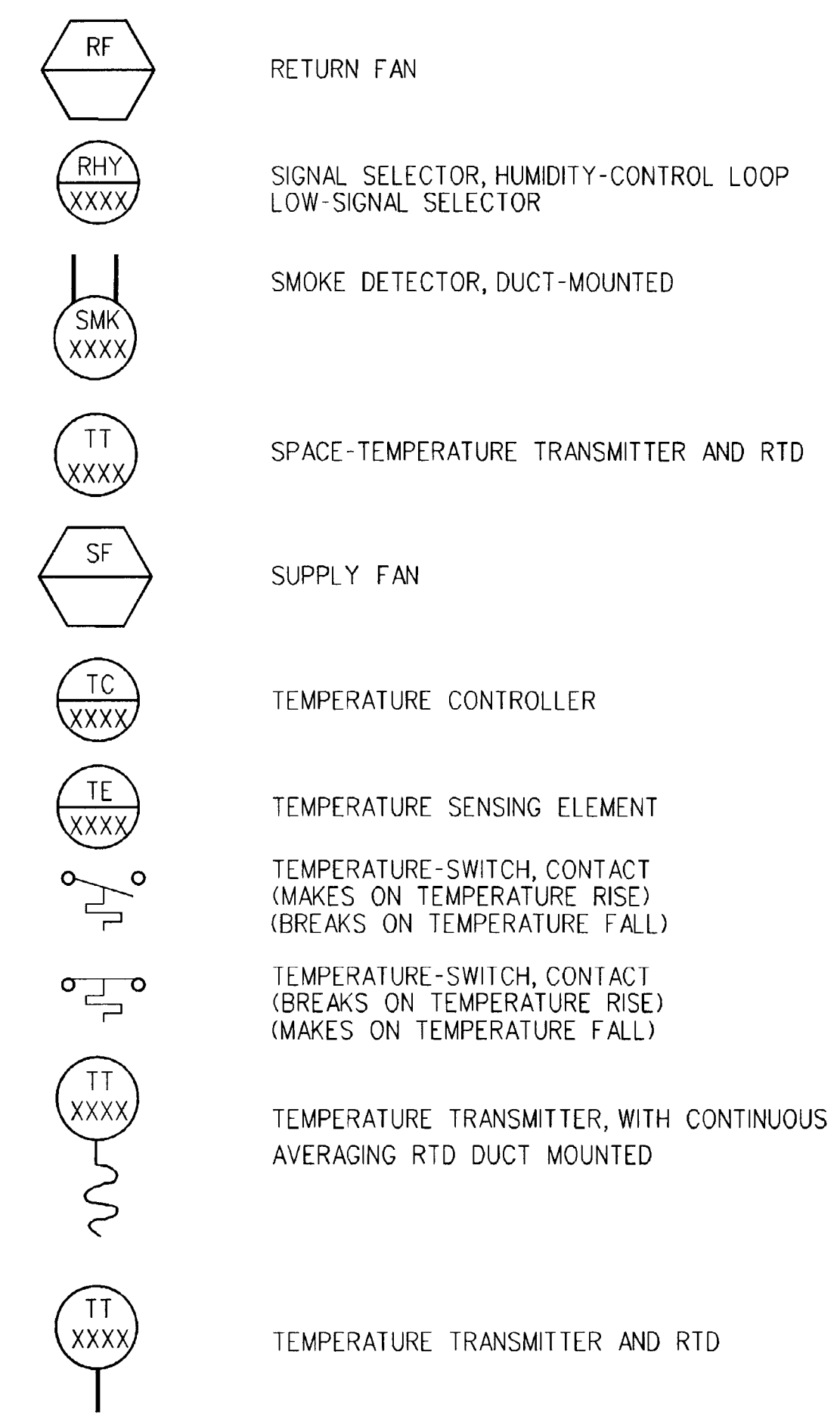
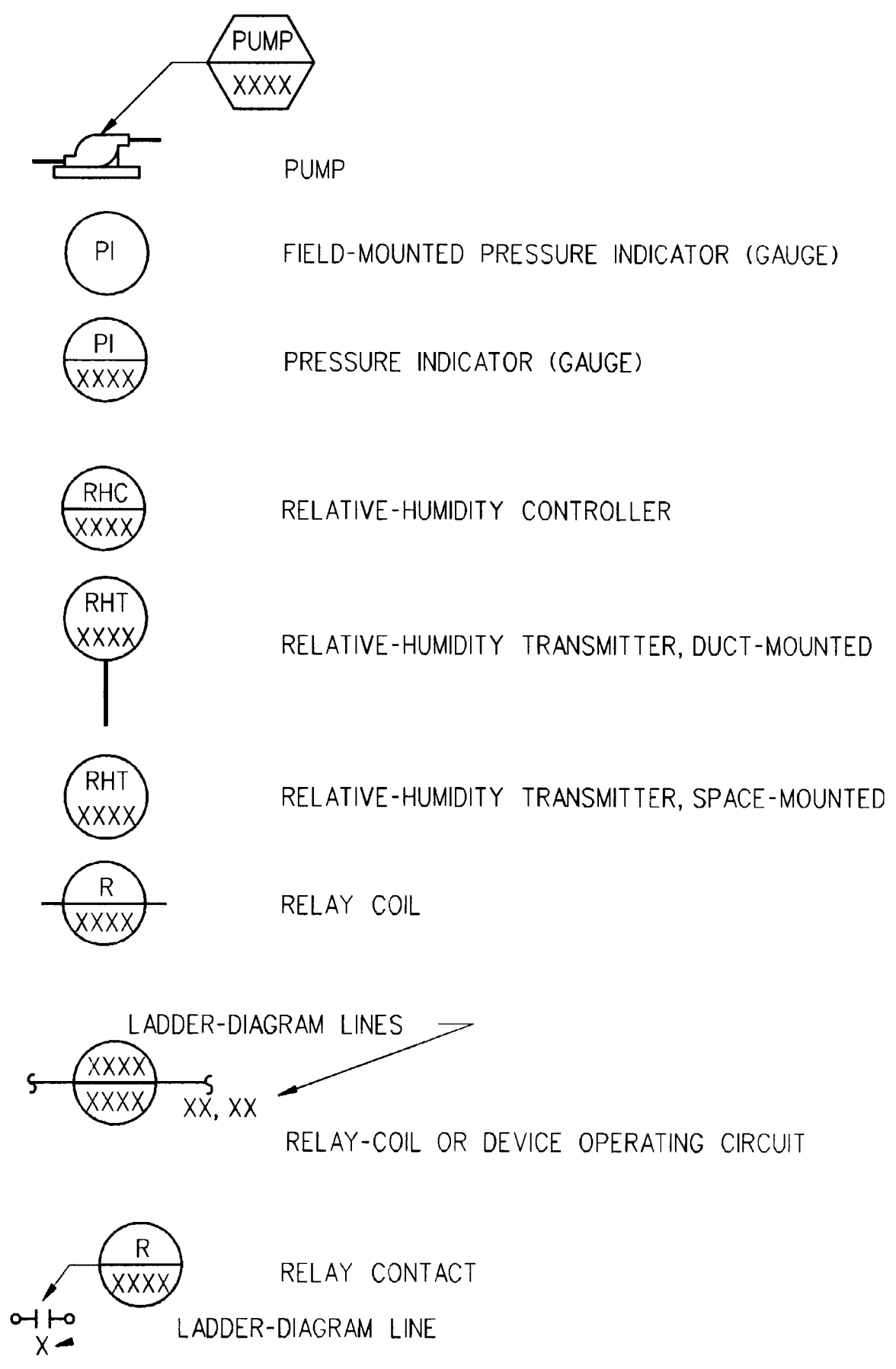


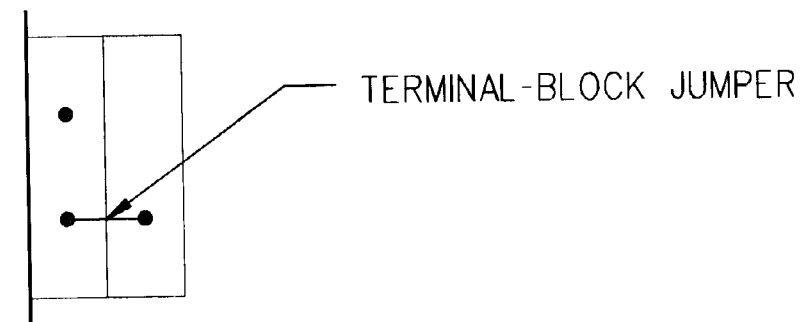
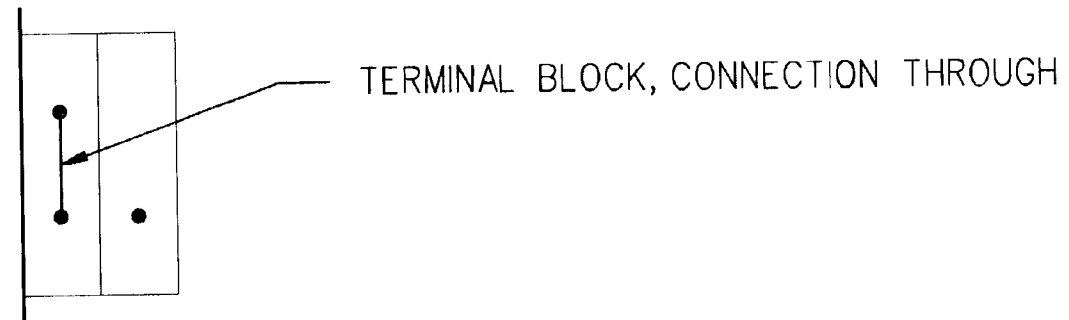
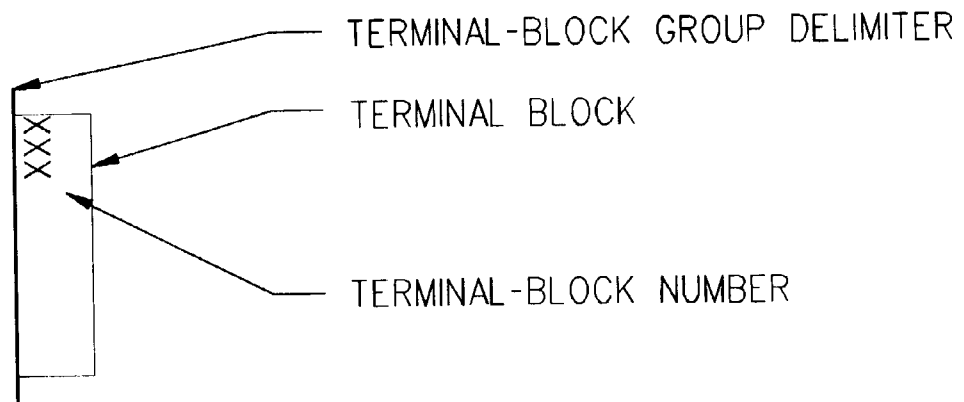
	COOLING-TOWER CELL
	CURRENT-TO-PNEUMATIC TRANSDUCER
	DAMPER, OPPOSED-BLADE WITHOUT SEALS
	DAMPER, OPPOSED-BLADE WITH SEALS
	DAMPER, PARALLEL-BLADE WITHOUT SEALS
	DAMPER, PARALLEL-BLADE WITH SEALS
	DEVICE SYMBOL, FIELD-MOUNTED
	DEVICE SYMBOL, PANEL-MOUNTED
	DIFFERENTIAL-PRESSURE INDICATOR
	DIFFERENTIAL-PRESSURE SWITCH
	DIFFERENTIAL-PRESSURE TRANSMITTER

	DUAL-DUCT BOX, CONSTANT VOLUME
	ECONOMIZER CONTROLLER
	ELECTRIC-SOLENOID-ACTUATED PNEUMATIC VALVE
	ELECTRIC LINES (LADDER DIAGRAMS AND SCHEMATICS)
	ELECTRONIC SIGNALS (SCHEMATICS)
	END SWITCH
	EXHAUST FAN
	FAN
	FIELD-DEVICE CONTACT
	FIELD-DEVICE TERMINAL

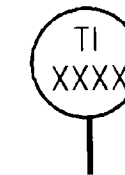




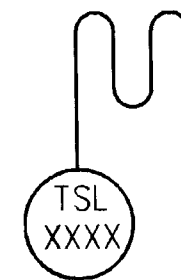




THERMOMETER, AVERAGING



THERMOMETER, NON-AVERAGING



THERMOSTAT, LOW-TEMPERATURE PROTECTION



THERMOWELL



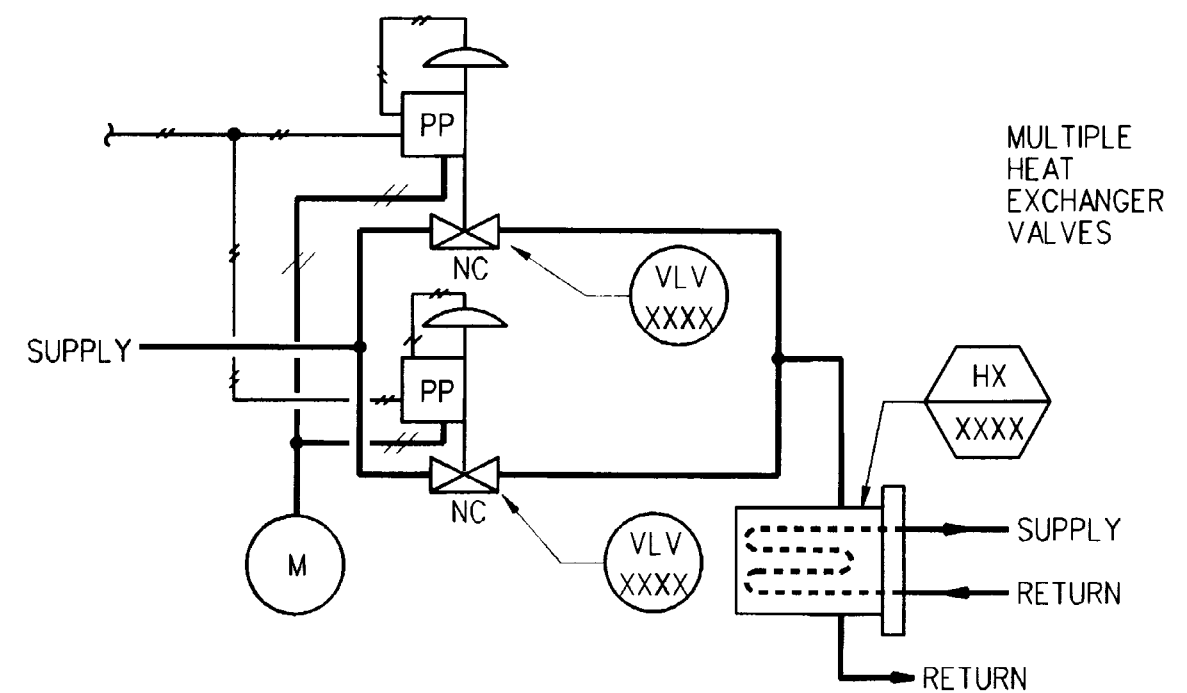
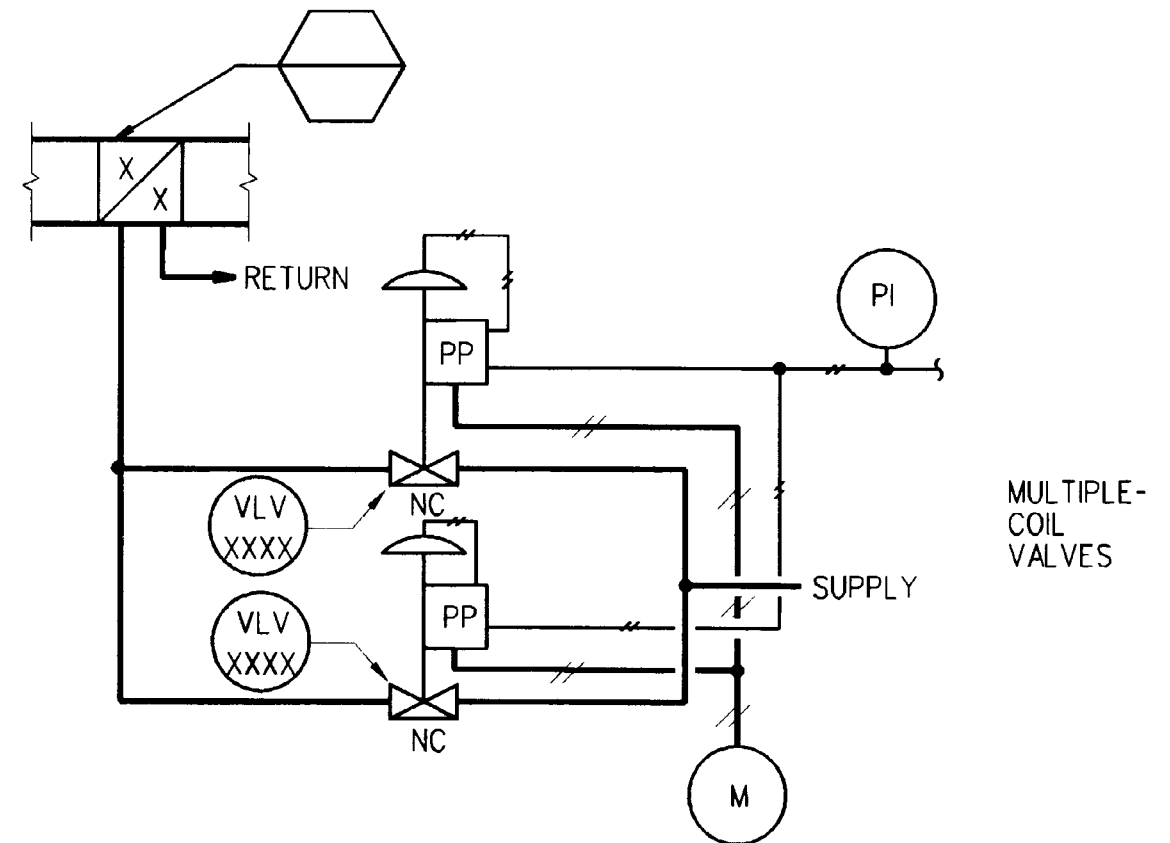
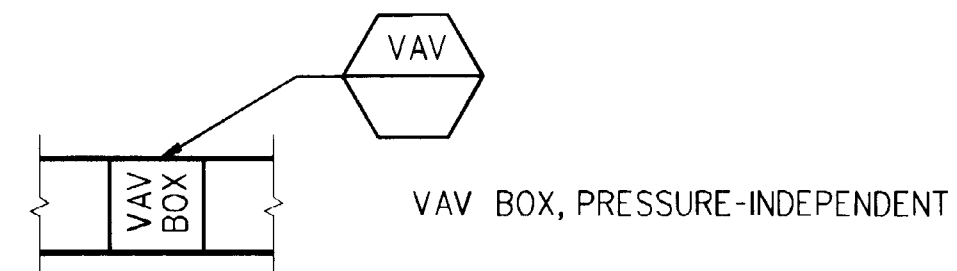
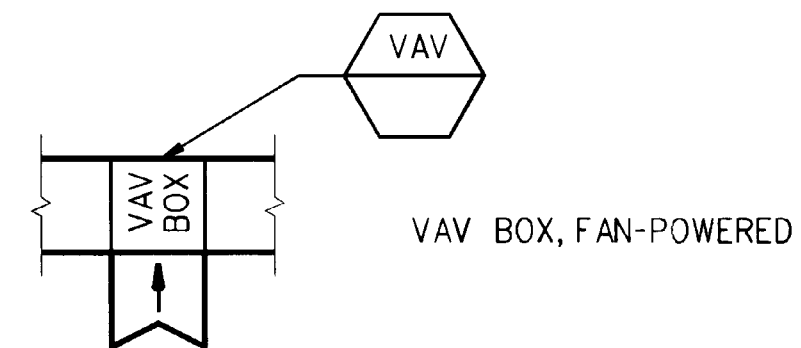
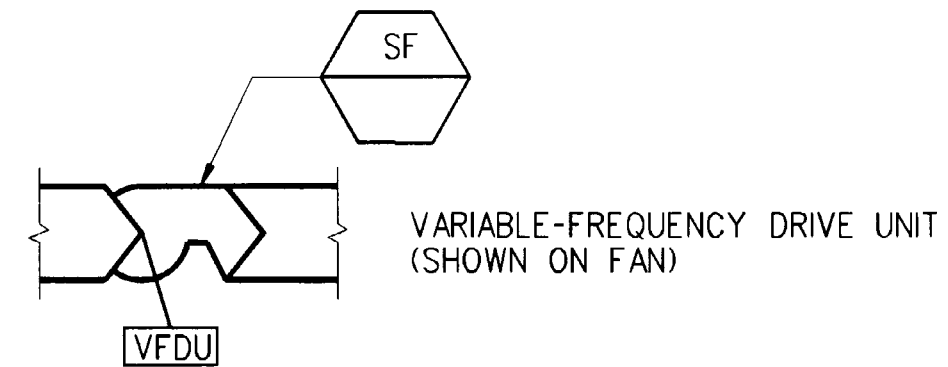
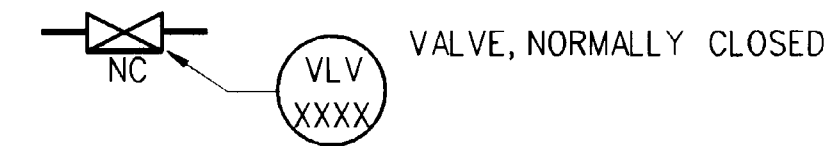
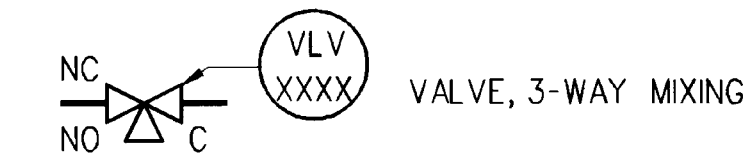
TIME CLOCK

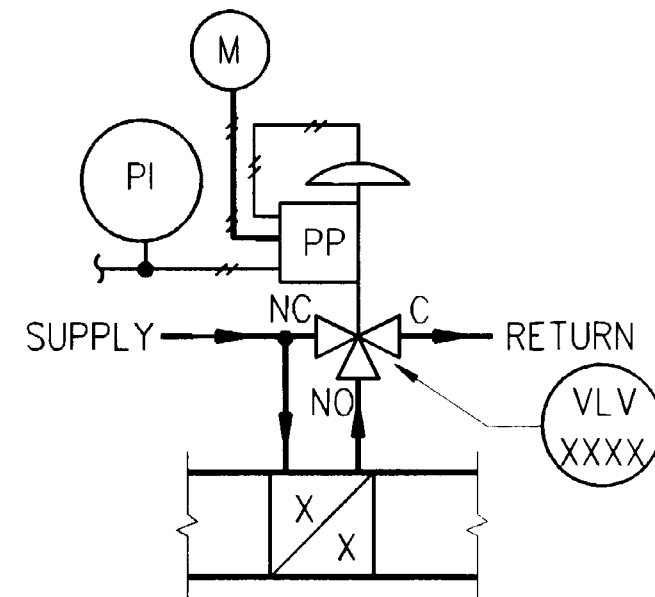


TIME-DELAY RELAY

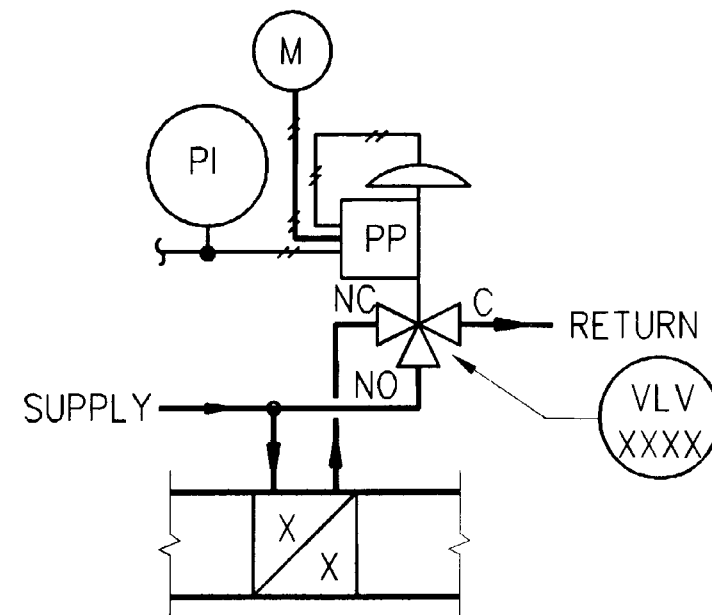


SIGNAL SELECTOR, TEMPERATURE-CONTROL LOOP, HIGH-SIGNAL SELECTOR





PNEUMATIC
3-WAY MIXING VALVE
PIPED NORMALLY OPEN IN
A BYPASS APPLICATION



PNEUMATIC
3-WAY MIXING VALVE
PIPED NORMALLY CLOSED
IN A BYPASS APPLICATION

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TM 5-815-3

Heating, Ventilating and Air Conditioning *HVAC Control Systems

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

**Chapter 6, Bibliography
and Glossary**